RIWAYAT KOMUNIKASI JURNAL

Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Dr. Ir. Nurlita Pertiwi, MT.

New corresponding author confirmation

1 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 20 Jul1 2021 16.09

Kepada: Nurlita Pertiwi <nurlita.pertiwi@unm.ac.id>

Dear Dr. Nurlita Pertiwi,

The PDF your submission entitled: Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia is ready for viewing.

Click this link to confirm:

https://www.editorialsystem.com/jeeng/article/correspondingAuthorConfirmation/978869/b5fb091827f8a18231da30f6773b2e53/

Editorial System of Journal of Ecological Engineering

ANALYSIS OF RIVERBANK STABILITY DUE TO BAMBOO VEGETATION IN WALANAE RIVER, SOUTH SULAWESI, INDONESIA

Nurlita Pertiwi, Bakhrani A. Rauf, Mithen

Engineering Faculty, Universitas Negeri Makassar

E-mail : nurlita.pertiwi@unm.ac.id

ABSTRACT

Bamboo vegetation is an endemic plant in Indonesia that grows on riverbanks. These plants have the potential to increase shear resistance due to the bond between the roots and soil. However, the weight of the plants triggers river bank sliding. Therefore in developing the riparian ecological function, it is necessary to maintain the plants without neglecting the risk of physical damage to the river. This study aims to estimate the risk of riverbank sliding due to the presence of bamboo plants by utilizing the bamboo vegetation conditions on the Walanae River. This was carried out on a riverbank in the middle area, 42.4 km along the administrative area of Soppeng Regency. The stem diameter of the plant was measured in 46 clumps and used as samples on the riverbanks and the result obtained was the basis for estimating its weight. Furthermore, numerical analysis was carried out by taking into account the load and shear resistance on the slope, which includes weight of the plant. The results of the analysis showed that in using bamboo plants as river reinforcement, the slope angle should be considered. Therefore, this study provides strength for the use of bamboo vegetation in riverbank protection. However, the interaction of flow dynamics and vegetation characteristics needs to be considered in future studies.

Keyword : Slope, diameter, weight of bamboo, Walanae River

Introduction

As an ecological sub-system, riverbanks are very vulnerable to degradation, due to its internal characteristics combination and flow dynamics [1]. Internally, it is characterized by soil, vegetation and aquatic conditions of the river, while externally, the dynamics of river flow are caused by high rainfall, floods and sediment transport. This combination leads to the occurrence of erosion and riverbank collapse [2]. Meanwhile, the function of the riverbank as a regulator of river flow depends on its maintenance [3]. Ecologically, the river bank also acts as a riparian and is a transition zone in the aquatic zone, which is always wet with a terrestrial zone that sometimes experiences either wet or dry conditions [4].

50 years ago, structural patterns were developed as protection for riverbanks in Indonesia. For this reason, construction of concrete embankments, Kribs and river gabions were the main choices due to the ease of work. However, facts in many places have showed that flow dynamics undermine this protective construction after a period of five to ten years. For this reason, the utilization of vegetation as cliff protection is relatively not carried out. Therefore, nonstructural management is an approach in cliff protection to control erosion [5] and the dual role of riparian vegetation is both ecological and mechanical. Ecologically, plants in this zone are able to play a role in purifying river water, while the vegetation plays a role in water infiltration and is an indicator of the hydrological condition of the river ecosystem. Meanwhile,

mechanically, riparian vegetation reduces the risk of erosion by decreasing flow velocity and increasing the lateral channel stability of riverbank [6].

Several countries have developed riverbank protections by maintaining local vegetation on riparian. This is because previous studies have shown that riparian vegetation reduces the risk of riverbank landslides. Furthermore, the presence of trees and grass on the riverbank increases the safety factor or reduce the risk of its collapse [7], while the riverbank root systems improve stability and maintain bank geometric conditions [8]. The strengthening mechanism of the cliffs with the presence of plant roots is its ability to act as anchors on the ground. Therefore, they are able to support the riverbank soil mass and the vegetation roots produce a stronger soil matrix and increase its stability against the risk of collapse [9]. Although, the hydrodynamic model of river flow is influenced by riverbank vegetation, this plant spreads the flow pattern in other to reduce speed. As a result, there is a kinetic decrease in soil mass, which reduces the risk of its release on riverbanks [10].

However, the interaction between water flow and vegetation on the riverbank was also analyzed with a mechanical approach. This is because, increasing shear forces due to plant growth leads to a rise in the value of safety factor at a certain slope. Furthermore, plant growth, which includes roots, twigs and leaves practically increases soil mass. Therefore, vegetation growth increases the risk of landslides [11] [12].

This study focuses on the risk of cliff collapse due to the growth of bamboo plants along the river. The bamboo in Indonesia, which grows with various species, develops rapidly due to the dependence of the rhizome root system. Meanwhile, the widespread distribution of underground roots when not controlled, cause sprouts to grow in unwanted places [13] and its sustainability is due to poor maintenance or improper destruction. Bamboo is an important part of various community activities such as building houses, traditional marriage ceremonies and death. Furthermore, its shoots are used as local food ingredients.

In this study, the destabilization of riverbanks by bamboo growth was visually assessed. The increase in block weight which was observed due to the increased soil mass and plant weight contributed to the addition of shear forces therefore, the risk of collapse was even greater. In the slope stabilization study, the mass collapse was assessed based on the value of safety factors, which when greater than 1.25 indicates cliff collapse [14]. Furthermore, bamboo growth was characterized by an increase in plant weight. Therefore, the study of the biomass of bamboo plants may be estimated by its diameter. The weight of bamboo as input to the tree surcharge is described in Figure 1.

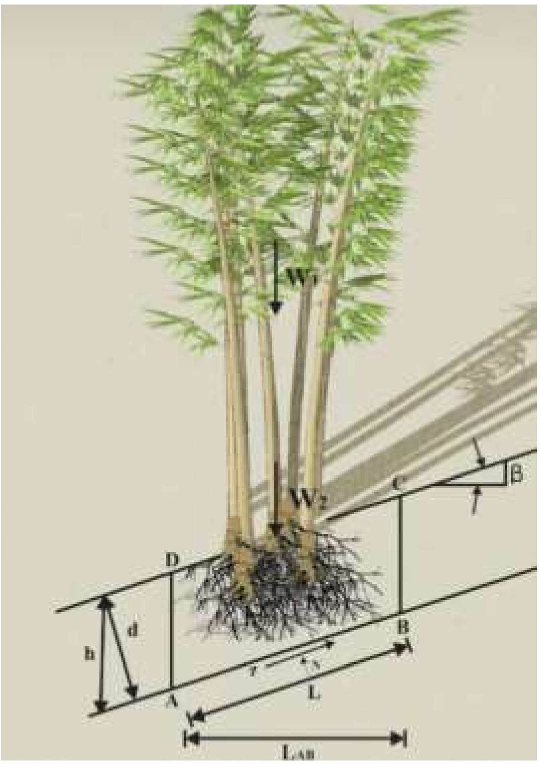

Figure. 1. Description of Plant Weight on Cliff Stability,

Method

Research locations

The location of this study was the Walanae watershed which intersects the administrative area of Soppeng Regency. The Walanae River as the focus of this study has a watershed area of 740km2 and a length of 250km, which flows from south to north towards the Lake Tempe alluvial.

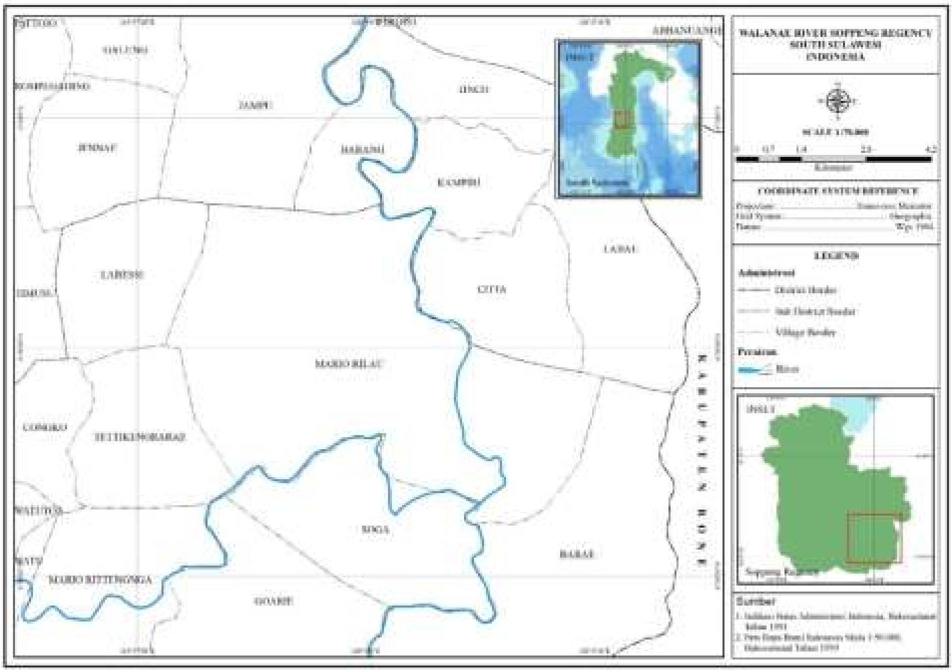

Figure. 2. Field Site of Walanae River

Sampling procedure

Measurement of bamboo characteristics was carried out in January 2020 - March 2020. The middle area of the Walanae River was chosen as the sampling location with a river length of 42.4km and was further divided into eight glands, following the direction of the water flow. Meanwhile, the bamboo clumps sampled were more than 300m apart from other samples. A description of the location for the collection and number of samples is presented in the table below.

Table 1. Sampling point

No	Side	Location	Total samples	Coordinate
1	Left	Marioritengnga Village	3	4°29'18.9"S 119°57'44.0"E
	Right	Goarie Village	2	4°28'42.3"S 119°58'09.3"E
2	Left	Mariorilau Village	2	4°28'01.9"S 119°59'17.7"E
	Right	Soga Village	5	4°27'54.3"S 119°59'28.8"E
3	Left	Soga Village	3	4°28'14.6"S 119°59'03.1"E
	Right	Barae Village	2	4°28'40.6"S 120°03'31.8"E
4	Right	Mariorilau Village	6	4°27'45.9"S 120°01'09.4"E
	Left	Barae Village	4	4°27'25.6"S 120°01'05.6"E
5	Right	Mariorilau Village	3	4°27'00.0"S 120°01'01.7"E
	Left	Citta Village	5	4°26'52.7"S 120°01'08.8"E
6	Right	Barang Village	3	4°23'55.5"S 120°00'25.0"E
				4°24'32.3"S 120°00'05.4"E
	Left	Kampiri Village	2	4°24'33.8"S 120°00'08.3"E
7	Right	Jampu Village	3	4°23'24.3"S 119°59'33.7"E
				4°23'17.2"S 119°59'38.6"E
	Left	Citta Village	3	4°26'58.6"S 120°01'03.5"E
Total samples			46	4°26'58.6"S 120°01'03.5"E

Retrieval of pile diameter data at a height of 150cm ± 5cm (D) using a caliper at three observation points [15]. (Figure 3)

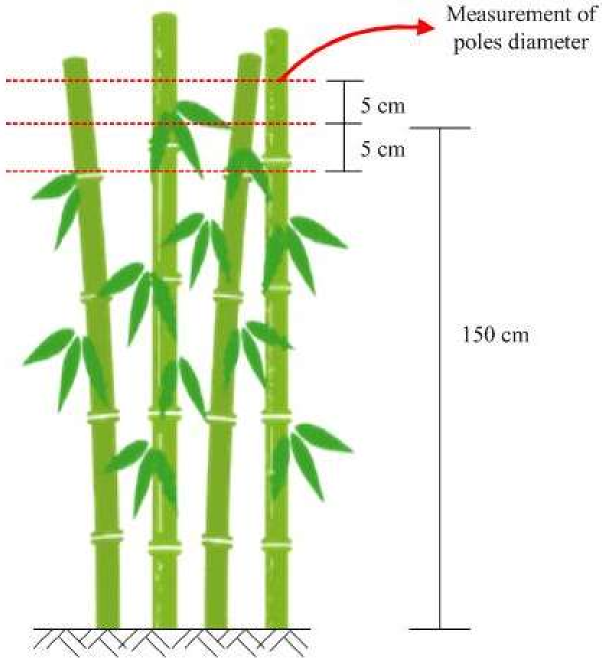

Figure 3. Measuring Points of Polishing Diameter

The average value of bamboo diameter forms the basis for calculating the total plant weight using the allometric biomass equation [15] (Eq.1).

$W_{est} = 0.348 \text{ x } D^{1.830}$……………………………………..(1)

Statistical analysis was carried out to ascertain the standard deviation of the diameter and weight of bamboo plants for each clump. From the results, three types of bamboo were obtained, namely small, medium and large bamboo based on their weight category.

Slope stability study

The numerical test of slope stability using secondary data on soil properties in Soppeng Regency is shown in Table 1. The test was carried out using the formula for the ratio of shearing resistance to force [8] [9]. The simulation of the safety factor calculation based on the angle of the slope and size of the bamboo led to the risk of riverbank sliding and a value greater than 1.25 indicates cliff collapse [14].

$Fs = \frac{S}{\tau} = \frac{(c' + c_s)L + (W_s' + W_t)\cos\beta \tan\emptyset'}{(W_s + W_t)\sin\beta}$………………(2)

The determination of the input values is presented in the table below.

Table 2. Source of secondary data

Variables	Unit	Value	Source
c’ (cohesion soil effective)	kPa	14.7	Soil testing data in Walanae River (2018)
c_s (apparent cohesion due to root)	kPa	7.2	[16]

L (bamboo root depth)	m	0.3	[17]
W’s (unit weight of soil minus buoyancy)	kN/m2	Equation $(\partial s - \partial w)h$ ∂s = 13.83 kN/m3 ∂w = 9.8 kN/m3	∂s from soil testing data in Walanae River (2018)
W’s (unit weight of soil)	kN/m2	Equation $(\partial s)h$	
B (slope)	º	simulation	
Ø’ (friction angle)	º	34.83	Soil testing data in Walanae River (2018)

Results and Discussion

Characteristics of bamboo vegetation in Riparian

Bamboo plants were discovered along the Walanae River and the results of this study showed that most of the bamboo plants were the result of 3-5years community culture (Figure 4). It is a commodity with a high selling value, due to its very intensive use, both as building materials for houses on stilts for residents in Soppeng and Wajo districts, traditional events, or for other purposes. People tend to choose riverbanks for planting bamboo, because their crops are easily transported to other locations via rivers and farmers also use the flow of water to transport bamboo to producers. In addition, this plant has resistance to standing water due to flooding therefore, it is considered suitable for planting in riparian areas.

Figure 4. Bamboo groves on the banks of the Walanae river

The results of measuring the diameter of the bamboo clump compiler were the basis for calculating its weight. The bamboo grove includes a number of polishes that vary between 16-27 stems with a diversity of 3.2. Furthermore, the moderate weight of bamboo ranged between 35.51kg and 98.94kg as shown in Table 3 and 4.

Table 3. Statistics of bamboo Characteristic

Statistical	Number of poles	West (kg)
Max	27	98.94
Min	16	35.51

Standard Deviation	3.20	15.09

Table 4. Statistics of bamboo Weight

Statistical	West (Kg)
Mean	59.92
Median	58.23
Percentil 25	48.06
Percentil 50	58.23
Percentil 75	71.59

Percentile analysis was the basis for the division into large (Plarge), medium (Pmed) and small (Psmall) categories. Table 5. shows the frequencies for the three bamboo sizes.

Table 5. The frequency of bamboo in three categories

Category	Value	Frequency
Psmall	West<48.06 kg	11
Pmed	48.06 kg ≤ West ≤ 71.59 Kg	24
Plarge	West > 71.59 Kg	11

To facilitate the analysis of the differences between the three categories, a boxplot was used to illustrate the number of stems and weight estimates. (Figure 5 and 6)

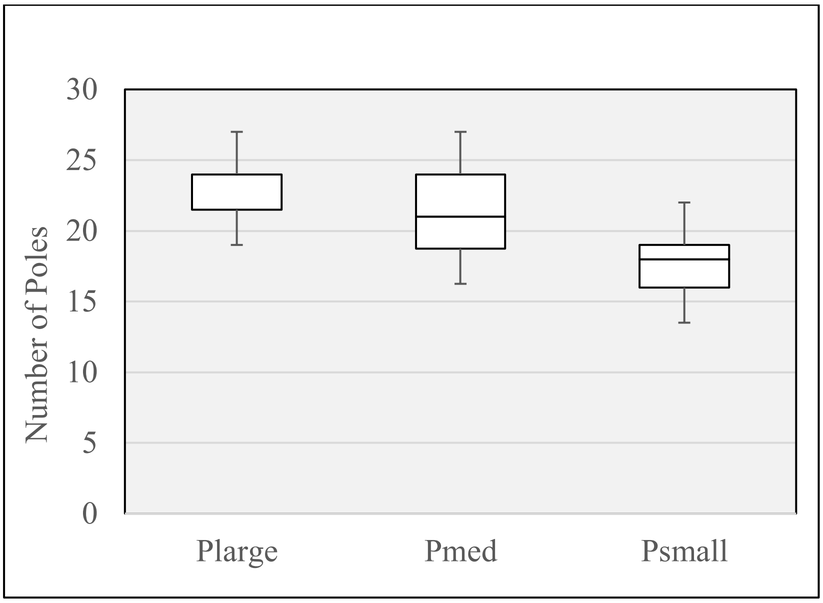

Figure 5. Boxplot Number of Poles

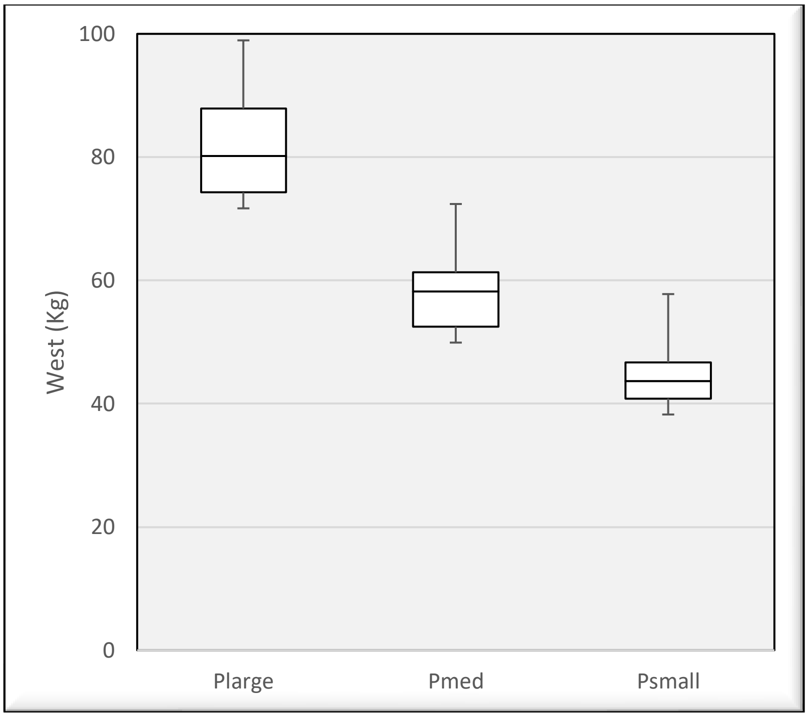

Figure 6. Boxplot Weight of bamboo

Figure 5 shows that the number of bamboo stalks in Plarge and Pmed were relatively the same although, the Psmall group had a relatively smaller number of stems. From the weight analysis of bamboo, it was clear that the difference in weight between the three groups, namely Plarge, Pmed and Psmall were centered on a value between 74.28Kg and 87.86Kg, 52.60Kg and 61.31Kg and 40.83Kg and 46.69Kg, respectively. This analysis results indicate that the number of stems was not the main cause of the increase in weight but that the diameter of the constituent stems was also a factor. Furthermore, the mean value was determined as the weight of each group for the calculation of the estimated slope stability for Plarge, Pmed and Psmall as 43.63 kg, 58.23 kg and 80.22 kg, respectively.

Slope Stability Estimation

Slope stability is an important factor in riverbank protection meanwhile, vegetation existence on riverbanks is also one of the factors that reduce slope stability. Therefore, the greater the soil mass, the higher the potential of increasing the risk of landslides. This was exacerbated by the addition of vegetation mass which increases along with growth. Furthermore, the estimated weight which refers to the diameter of the constituent rods was proven to have an effect on the risk of landslides. Therefore, the value of the safety factor is an indicator of the level of slope stability.

The results of the safety factor analysis on three bamboo groups with various slopes are presented in Figure 7

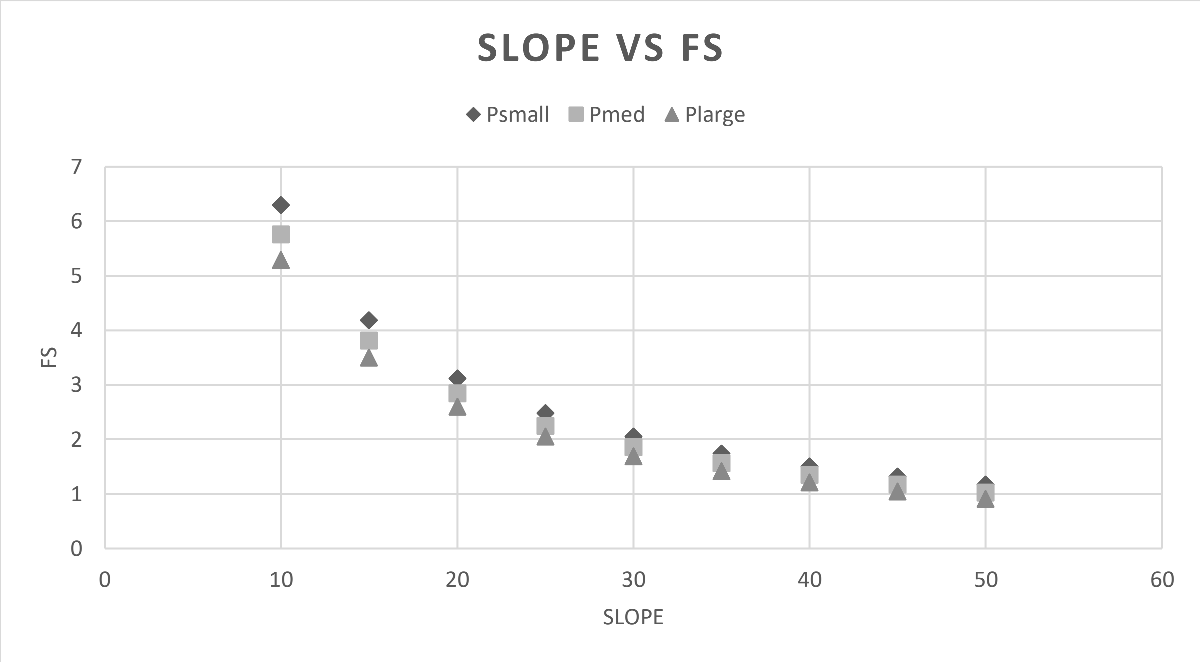

Figure 7. Estimated Safety Factor due to the weight of bamboo

At the slope angle of 10º, it is clear that the difference in the safety factor between the bamboo groups varied between 5.29 and 6.29. Meanwhile, at angles of 15º, 20º, 35º and 30º, the difference in the value of the safety factor was decreased. Even at a slope angle above 40º, the three types of bamboo produces an Fs value less than 1.2. This implies that bamboo contributes to slope collapse at angles above 40º.

Discussion

Riverbanks that are equipped with riparian ecosystems contribute to the physical quality of the river. This premise was supported by the Hubble study [18], which stated that plant roots contribute to the reduced risk of landslides due to root strengthening. Therefore, the riparian root system was effective in increasing slope stability. Furthermore, the growth of riparian vegetation which usually acts as a floodplain is able to maintain the quality of the river. Sedimentation as a series of erosion events is minimized by the presence of vegetation. As a result, the river bed topography was better preserved and maintained river capacity [19].

Mechanically, the presence of riparian plants was able to reduce the flow momentum against the river bank, while plant roots played a role in reducing the drag coefficient of natural channels, causing a decrease in flow rate. Boothroyd discovered that riparian plants also varied the drag coefficient of the riverbank. Therefore, the existence of bamboo vegetation is important with its extensive root system [20]. The combination of the potential of the roots as a sediment retainer, soil binder and reducing flow momentum was the main reason for its maintenance on the riverbanks.

The discoveries of this study practically provided a guide for non-structural river management methods where bamboo vegetation is one of the right choices. Bamboo with its distinctive morphology made of several poles is relatively easy to manage. Therefore, harvesting it by releasing some of its parts is a community habit and this harvest pattern is an effort to prevent the risk of increasing plant weight.

Erosion events on cliffs with large slopes occur with a failure mechanism which is initiated by toe erosion. Shu [21] described that the collapse rate of riverbanks has a positive correlation with flow velocity, water depth and soil bearing capacity. However, this study does not describe the risk of landslides due to the vegetation along the riverbanks.

Figure 8, describes the process of erosion and cliff collapse. Due to the frictional force of water flow against the foot of the cliff, the erosion process began with the peeling of the soil at the foot of the cliff. (Ii) With the presence of bamboo, the roots of the plants could not carry them, which slowly cause them to collapse. This implies that the large weight as a burden at the foot of the cliff triggered the collapse. As a result, cliffs collapse and the vegetation on the riverbanks will also be released.

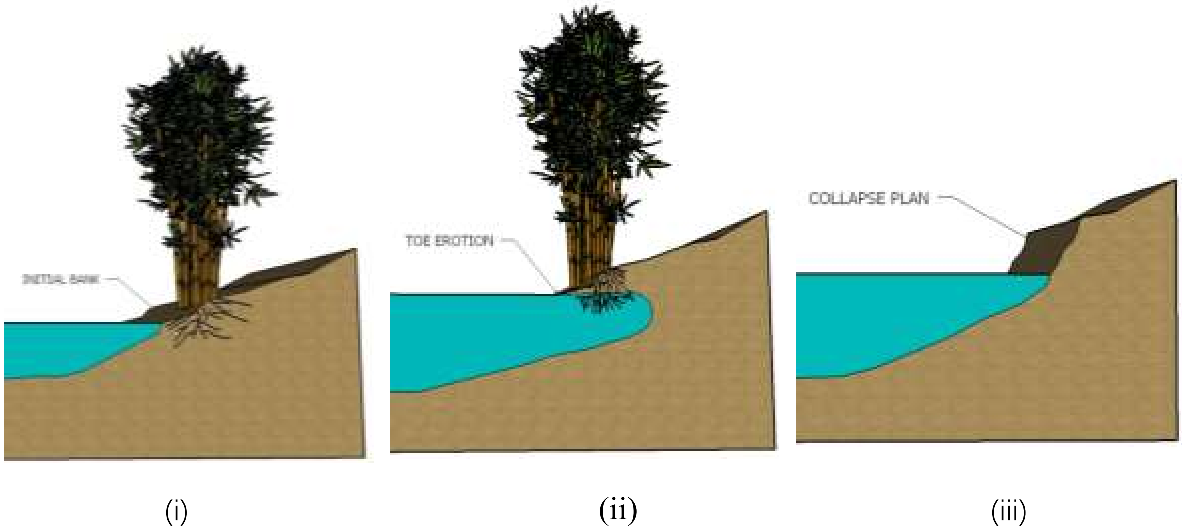

Figure 8. The mechanism of cliff collapse on a riverbank

Cliff erosion may be controlled by maintaining bamboo vegetation on the riverbanks. Bamboo as an endemic to Indonesia is easily planted on riverbanks with moisture conditions and suitability for soil characteristics. Furthermore, its benefits for social activities are very important and its socio-economic importance to the community is the reason for its preservation along the riverbanks.

Conclusion

Based on the results obtained and numerical analysis of riverbank stability, the following conclusions were made:

1. Bamboo vegetation on the banks of the Walanae river is divided into three categories, namely small, medium and large bamboo weighing 43.63kg, 58.23kg and 80.22kg, respectively. Furthermore, it consists of 16 to 27 polishes.
2. The results of the numerical analysis indicate that the presence of bamboo vegetation increases the risk of cliff landslides. Therefore, as its weight increases, it contributes to a decrease in the value of the safety factor and at a slope angle above 40°, the weight of its vegetation has the potential to cause landslides.

Acknowledgement

This work was supported by the "PNBP Percepatan Profesor UNM" under grant 2400/UN.36.11/LP2M/2020

Reference

[1] J. M. McMahon *et al.*, "Vegetation and longitudinal coarse sediment connectivity affect the ability of ecosystem restoration to reduce riverbank erosion and turbidity in drinking water," *Sci. Total Environ.*, vol. 707, p. 135904, 2020.

[2] A. Recking, G. Piton, L. Montabonnet, S. Posi, and A. Evette, "Design of fascines for riverbank protection in alpine rivers: Insight from flume experiments," *Ecol. Eng.*, vol. 138, pp. 323–333, 2019.

[3] C. Lu, S. Chen, Y. Jiang, J. Shi, C. Yao, and X. Su, "Quantitative analysis of riverbank groundwater flow for the Qinhuai River, China, and its influence factors," *Hydrol. Process.*, vol. 32, no. 17, pp. 2734–2747, 2018.

[4] K. Schmitt, M. Schäffer, J. Koop, and L. Symmank, "River bank stabilisation by bioengineering: potentials for ecological diversity," *J. Appl. Water Eng. Res.*, vol. 6, no. 4, pp. 262–273, 2018.

[5] N. W. Chan, A. Ab Ghani, N. Samat, N. N. N. Hasan, and M. L. Tan, "Integrating structural and non-structural flood management measures for greater effectiveness in flood loss reduction in the Kelantan River Basin, Malaysia," in *AWAM International Conference on Civil Engineering*, 2019, pp. 1151–1162.

[6] K. Västilä and J. Järvelä, "Characterizing natural riparian vegetation for modeling of flow and suspended sediment transport," *J. Soils Sediments*, vol. 18, no. 10, pp. 3114–3130, 2018.

[7] A. Collison and A. Simon, "Beyond Root Reinforcement: the hydrologic effects of riparian vegetation on riverbank stability," in *Wetlands Engineering & River Restoration 2001*, 2001, pp. 1–12.

[8] B. Abernethy and I. D. Rutherfurd, "Does the weight of riparian trees destabilize riverbanks?," *Regul. Rivers Res. Manag. An Int. J. Devoted to River Res. Manag.*, vol. 16, no. 6, pp. 565–576, 2000.

[9] T. H. Wu and A. Watson, "In situ shear tests of soil blocks with roots," *Can. Geotech. J.*, vol. 35, no. 4, pp. 579–590, 1998.

[10] N. Pollen-Bankhead and A. Simon, "Hydrologic and hydraulic effects of riparian root networks on streambank stability: Is mechanical root-reinforcement the whole story?," *Geomorphology*, vol. 116, no. 3–4, pp. 353–362, 2010.

[11] J. R. Greenwood, J. E. Norris, and J. Wint, "Assessing the contribution of vegetation to slope stability," *Proc. Inst. Civ. Eng. Eng.*, vol. 157, no. 4, pp. 199–207, 2004.

[12] N. Pollen and A. Simon, "Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model," *Water Resour. Res.*, vol. 41, no. 7, 2005.

[13] T. Liang, L. I. Pingheng, Z. Guomo, Z. Yufeng, and L. I. Chong, "A review of research about rhizome-root system in bamboo forest," 浙江农林大学学报, vol. 36, no. 1, pp. 183–192, 2019.

[14] WSDOT, “Geotechnical design manual M46-03.” Washington State Department of Transportation Olympia, WA, 2005.

[15] S. D. Baharuddin and D. Malamassam, “Kaimuddin. 2013. Allometric equation for estimating the total biomass and carbon stock in Parring Bamboo (Gigantochloa atter) from community forests.” 2016.

[16] S. De Baets, D. Torri, J. Poesen, M. P. Salvador, and J. Meersmans, “Modelling increased soil cohesion due to roots with EUROSEM,” *Earth Surf. Process. Landforms J. Br. Geomorphol. Res. Gr.*, vol. 33, no. 13, pp. 1948–1963, 2008.

[17] C. Lin, Y. Yang, J. Guo, G. Chen, and J. Xie, “Fine root decomposition of evergreen broadleaved and coniferous tree species in mid-subtropical China: dynamics of dry mass, nutrient and organic fractions,” *Plant Soil*, vol. 338, no. 1–2, pp. 311–327, 2011.

[18] T. C. T. Hubble, B. B. Docker, and I. D. Rutherfurd, “The role of riparian trees in maintaining riverbank stability: a review of Australian experience and practice,” *Ecol. Eng.*, vol. 36, no. 3, pp. 292–304, 2010.

[19] A. Vargas Luna, “Role of vegetation on river bank accretion,” 2016.

[20] R. J. Boothroyd, R. J. Hardy, J. Warburton, and T. I. Marjoribanks, “Modeling complex flow structures and drag around a submerged plant of varied posture,” *Water Resour. Res.*, vol. 53, no. 4, pp. 2877–2901, 2017.

[21] A. Shu, G. Duan, M. Rubinato, L. Tian, M. Wang, and S. Wang, “An experimental study on mechanisms for sediment transformation due to riverbank collapse,” *Water*, vol. 11, no. 3, p. 529, 2019.

UNM

Nurlita UNM <nurlita.pertiwi@unm.ac.id>

Version Received-- JEENG-02554-2-21-01

2 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 25 Juli 2021 09.59
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: Nurlita Pertiwi <nurlita.pertiwi@unm.ac.id>
Cc: <kontakt@editorialsystem.com>, Bakhrani Rauf <bakhrani@unm.ac.id>, Mithen Lullulangi <mithen@unm.ac.id>

Dear Dr. Nurlita Pertiwi,

The editor informs you about the progress your paper:
Manuscript ID: JEENG-02554-2-21-01
Type of manuscript: Research article
Title: Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia
Authors: Nurlita Pertiwi, Bakhrani Rauf, Mithen Lullulangi *
Received: 20 July 2021
E-mails: nurlita.pertiwi@unm.ac.id, bakhrani@unm.ac.id, mithen@unm.ac.id

We will continue processing your paper and will keep you informed about the submission status.

Kind regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Nurlita UNM <nurlita.pertiwi@unm.ac.id> 25 Juli 2021 10.32
Kepada: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>

Dear publisher.

Thank you very much for the news about the processing of my paper.

King regards

Nurlita Pertiwi

[Kutipan teks disembunyikan]

Nurlita UNM <nurlita.pertiwi@unm.ac.id>

Major Revisions— JEENG-02554-2-21-01

2 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 02 Agu 2021 09.59
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: Nurlita Pertiwi <nurlita.pertiwi@unm.ac.id>
Cc: <kontakt@editorialsystem.com>, Bakhrani Rauf <bakhrani@unm.ac.id>, Mithen Lullulangi <mithen@unm.ac.id>

Dear Dr. Nurlita,

I want to inform you about the progress of your paper :

The editor informs you about the progress your paper:
Manuscript ID: JEENG-02554-2-21-01
Type of manuscript: Research article
Title: Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia
Authors: Nurlita Pertiwi, Bakhrani Rauf, Mithen Lullulangi *
Received: 20 July 2021
E-mails: nurlita.pertiwi@unm.ac.id, bakhrani@unm.ac.id, mithen@unm.ac.id

Reviewers' comment has provide in the journal system
https://www.editorialsystem.com/jeeng/

Please revise the manuscript according to the reviewers' comments and upload the revised file within 14 days. Use the version of your manuscript found at the above link for your revisions, as the editorial office may have made formatting changes to your original submission. Any revisions should be clearly highlighted, for example using the "Track Changes" function in Microsoft Word, so that changes are easily visible to the editors and reviewers. Please provide a cover letter to explain point-by-point the details of the revisions in the manuscript and your responses to the reviewers' comments. Please include in your rebuttal if you found it impossible to address certain comments. The revised version will be inspected by the editors and reviewers.

Do not hesitate to contact us if you have any questions regarding the revision of your manuscript. We look forward to hearing from you soon.

Kind regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

JEENG-02554-2021-01_255715
883K

Nurlita UNM <nurlita.pertiwi@unm.ac.id> 10 Agu 2021 10.49
Kepada: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>

Dear publisher.

I submit the article revision and cover letter file in the attachment.

King regards

Nurlita Pertiwi

JEENG-02554-2021-01_255715
702K

Cover Letter Manuscript 123
26K

Review of Pertiwi et al. 2021

The manuscript entitled “Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia” deals with a technique of soil-bioengineering for stabilizing riverbank. The authors collected some data from the scientific community (i.e., root reinforcement quantification) and from technical report (relationships between weight and stem diameter). Then, they calculated the weight and applied a 1-D slope stability model. They neglect a lot of physical dynamics of riverbank vegetation (uprooting mechanisms during flood, flow resistance, windthrow, etc.).

In general, the manuscript deals with an interesting topic, namely the use of the bamboo vegetation for riverbank stability. Despite, it seems a well-done exercise that applied the Mohr-Coulomb approach rather than a piece of science. I think that improving the quality of figures and the text, the manuscript could be valid for a no-IF scientific journal.

Thus, this manuscript requests a significant revision for the publication step. More details into the document.

Comments

- Abstract

Line 15: "the bond between the roots and the soil" to "the roots".

Line 16: "river bank" I should use the same term for this physical mechanism. I should always use "riverbank".

Line 16: "river bank sliding" Could the authors better describe this failure?

Line 20: "middle area" Where?

Line 21: "46 clumps" How did the authors select them? Which is the discriminant factor?

Line 24: "river reinforcement" What does it mean?

- Introduction

The authors did not mention the term "soil bio-engineering". I think that it is a great forgetfulness (Bischetti et al., 2021, 2014; Rey et al., 2019).

In addition, the authors neglected some interesting works that summarises the state-of-the-art on the topic of streambank stability (Gasser et al., 2020, 2019).

Line 32: "degradation" What does it mean? Please, explain.

Line 39: "2018" to "2018)"

Line 40: "50 years...". This sentence should be moved to "Study site".

Line 46: "both ecological and mechanical" What does it mean? Please, explain.

Line 46: "purifying" What does it mean? Please, explain. References?

Line 69: "in Indonesia" Here, it is not necessary to dealt with the study area.

Line 83: Please, clarify which is the main objective and the secondary ones (maybe using a list).

- Materials and Methods

Line 87: "Research locations" to "Study area".

Line 89: "km2" Please, make attention on space and apex.

Figure 2: The figure is of poor quality, not so readable.

Line 94: Why in italic?

Table 1: It is not useful reporting the specific coordinates. Maybe, it is better to draw a map with the river and the samples sites.

Figure 3: Maybe, I should replace it with a real photo.

Line 104: Please, make attention on punctuation.

Line 107: The equation is unreadable.

Line 116: Why did the authors not use the 2.5D or 3D stability models (Chiaradia et al., 2016; Cislaghi et al., 2018, 2017; Dietrich et al., 2007)?

Line 117: The equation is unreadable.

Table 2: Did the authors take all data from the literature? Please, explain the measurements (for soil cohesion, the soil weight, etc.). Why did they use "7.2 kPa" for the root reinforcement?

- Results

Figure 4: Which is its utility?

Tables 3-4: They are not useful to the take-home-message of the paper.

Table 5: Including min, max and mean.

Figure 5: The figure could be improved.

Line 153: "Kg" to "kg". Please.

Line 161: "the greater the soil mass". What does it mean?

Line 163: "which" Insert a comma before.

Figure 7: The figure is of very poor quality. The distances among points are undetectable. I should insert a horizontal line at FS=1. Are there some points below this line?

- Discussion

The discussion is very general. I think that the mechanisms could be discussed before. A comparison with similar works of the literature is missing.

- Conclusions

I avoid the bullets list in the conclusions.

- References

Please, remove the reference to technical report (Baharuddin and Malamassam, 2013; Chan et al. 2019; Liang et al. 2019; Vargas Luna 2016)

References

Bischetti, G.B., De Cesare, G., Mickovski, S.B., Rauch, H.P., Schwarz, M., Stangl, R., 2021. Design and temporal issues in soil bioengineering structures for the stabilisation of shallow soil movements. Ecol. Eng. 169, 106309. https://doi.org/10.1016/j.ecoleng.2021.106309

Bischetti, G.B., Di Fidio, M., Florineth, F., 2014. On the origin of soil bioengineering. Landsc. Res. 39, 583–595. https://doi.org/10.1080/01426397.2012.730139

Chiaradia, E.A., Vergani, C., Bischetti, G.B., 2016. Evaluation of the effects of three European forest types on slope stability by field and probabilistic analyses and their implications for forest management. For. Ecol. Manag. 370, 114–129. https://doi.org/10.1016/j.foreco.2016.03.050

Cislaghi, A., Chiaradia, E.A., Bischetti, G.B., 2017. Including root reinforcement variability in a probabilistic 3D stability model. Earth Surf. Process. Landf. 42, 1789–1806. https://doi.org/10.1002/esp.4127

Cislaghi, A., Rigon, E., Lenzi, M.A., Bischetti, G.B., 2018. A probabilistic multidimensional approach to quantify large wood recruitment from hillslopes in mountainous-forested catchments. Geomorphology 306, 108–127. https://doi.org/10.1016/j.geomorph.2018.01.009

Dietrich, W.E., McKean, J., Bellugi, D., Perron, T., 2007. The prediction of shallow landslide location and size using a multidimensional landslide analysis in a digital terrain model, in: Proceedings of the 4th International Conference on Debrisflow Hazards Mitigation: Mechanics, Prediction, and Assessment (DFHM-4). Chengdu, China. pp. 10–13.

Gasser, E., Perona, P., Dorren, L., Phillips, C., Hübl, J., Schwarz, M., 2020. A new framework to model hydraulic bank erosion considering the effects of roots. Water 12, 893. https://doi.org/10.3390/w12030893

Gasser, E., Schwarz, M., Simon, A., Perona, P., Phillips, C., Hübl, J., Dorren, L., 2019. A review of modeling the effects of vegetation on large wood recruitment processes in mountain catchments. Earth-Sci. Rev. 194, 350–373. https://doi.org/10.1016/j.earscirev.2019.04.013

Rey, F., Bifulco, C., Bischetti, G.B., Bourrier, F., De Cesare, G., Florineth, F., Graf, F., Marden, M., Mickovski, S.B., Phillips, C., Peklo, K., Poesen, J., Polster, D., Preti, F., Rauch, H.P., Raymond, P., Sangalli, P., Tardio, G., Stokes, A., 2019. Soil and water bioengineering: practice and research needs for reconciling natural hazard control and ecological restoration. Sci. Total Environ. 648, 1210–1218. https://doi.org/10.1016/j.scitotenv.2018.08.217

Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Nurlita Pertiwi[1,]* Bakhrani Rauf[2], and Mithen Lullulangi[3]

[1,2,3] Civil engineering Education Faculty of Engineering, Universitas Negeri Makassar, Makassar, Indonesia

* **Correspondence:** Email: nurlita.pertiwi@unm.ac.id.

ABSTRACT

Bamboo vegetation is an endemic plant in Indonesia that grows on riverbanks. These plants have the potential to increase shear resistance due to the bond between the roots to the soil. However, an increase in plant weight due to its growth causes additional loads of soil. The condition triggers the release of soil on the slopes and causes riverbank sliding. Therefore, in developing the riparian ecological function, it is necessary to maintain the plants without neglecting the risk of physical damage to the river. This study aims to estimate the risk of riverbank sliding due to the presence of bamboo plants by utilizing the bamboo vegetation conditions on the Walanae River. This was carried out on the 42.4 km riverbank in the middle area of Walanae watershed. The researchers selected 46 clumps of *Parring Bamboo* (*Gigantochloa Atter*) as an endemic bamboo in this area and growing in the riverbank. The diameter of the bamboo trunk is the basis for an estimate of the weight of the bamboo clump. Furthermore, numerical analysis was carried out by taking into account the load and shear resistance on the slope, including the weight of the plant. The research results bamboo is feasible to be applied to riverbank protection using the soil bioengineering method. The bamboo weight, which is indicated by the number of poles and diameter, significantly affects the stability of the slope. Therefore, the prevention of rising weight by harvesting method is critical to consider in riverbank protection.

Keywords: slope, diameter, weight of bamboo, Walanae river

INTRODUCTION

As an ecological sub-system, riverbanks are very vulnerable to degradation due to their internal characteristics combination and flow dynamics (McMahon *et al.*, 2020). Environmental restoration of the river system is one of the ecological protection options by combining flow and soil characteristics (Rey et al, 2019). Moreover, the high sedimentation and slides are evidence of the decreasing of the riverbank quality. Internally, it is characterized by soil, vegetation, and aquatic conditions of the river.

In contrast, river flow dynamics are caused by high rainfall, floods, and sediment transport leads to erosion and riverbank collapse (Recking et al, 2019) . Meanwhile, the function of the riverbank as a regulator of river flow depends on its maintenance (Lu et al, 2018). Ecologically, the river bank also acts as a riparian and is a transition zone in the aquatic zone, always wet with a terrestrial area that sometimes experiences wet or dry conditions (Schmitt, et al, 2018).

The existence of vegetation on the banks of the river dramatically affects the physical processes of natural channels. The growth of plants make the contribution for riverbank stabilization. (Bischetti, et al, 2014). However, the process of protecting slopes and their stability and their relationship to plants has not been a serious concern. The presence of large trees increases the potential for slope movement Moreover, the dynamics of plant growth are very influential on the success of cliff protection (Cislaghi, et al, 2018). Therefore, temporal plant growth should be an essential consideration in soil bioengineering. The dynamics of root reinforcement are exciting studies in applying environmentally friendly cliff protection (Bischetti, et al, 2021).

The plant system that includes root, stem, and leaf has a contribution to the bank stability. This contribution can change in line with the characteristics of the stand and the nature of groundwater retention. The stem and leaf system can minimize splash erosion and reduce the risk of scouring the soil. Furthermore, the root system with its growth dynamics has raised many questions about the potential of roots to soil stability. Root growth contributes to soil shear resistance (Cislaghi, et al, 2017.

The ability of plants to maintain streambank conditions depends on the depth of their roots. While, the natural mechanism that occurs in vegetation can technically be related to the theory of channel hydraulics. The streambank resistance or cliff reinforcement is better with the presence of plant root networks. Plant roots that coincide with the soil shear plane cause a good interaction with soil reinforcement. On the other hand, plant roots increase the channel roughness increase. This condition causes a loss of energy in the flow and reduces the flow velocity. With these two mechanisms, plants strengthen riverbanks internally and externally. Plant roots also reduce external stresses due to river flow (Gasser *et al.*, 2019). .

The riverbank root systems also improve stability and maintain geometric bank conditions (Abernethy et al, 2000). The strengthening mechanism of the cliffs with the presence of plant roots is their ability to act as anchors on the ground. Therefore, they are able to support the riverbank soil mass, and the vegetation roots produce a more robust soil matrix and increase its stability against the risk of collapse (Wu et al, 1998). Although the hydrodynamic model of river flow is influenced by riverbank vegetation, this plant spreads the flow pattern in other to reduce speed. As a result, there is a kinetic energy decrease in soil mass, which reduces the risk of its release on riverbanks (Pollen et al, 2005).

The contradictory opinions about the role of plant roots on soil stability describe that: the dynamics of plants and their growth cause an increase in the risk of cliff slides (Cislaghi, et al, 2018).

The increase in lateral strength due to root growth is also an interesting consideration in the study of soil bioengineering (Dietrich, et al, 2007). Another, also described the potential for decreasing soil stability due to riparian plant root systems (Zhang, et al, 2020). . The intrinsic properties of the soil or its properties affect the erosion potential of the soil. However, the growth of the root system and the accumulation of litter can change the nature and structure of the soil, which can increase the potential for cliff erosion.

Plant growth is also considered a problem at the risk of rock slides. The interaction between water flow and vegetation on the riverbank was also analyzed with a mechanical approach. The increasing shear forces due to plant growth lead to a rise in the safety factor value at a certain slope. Furthermore, plant growth, which includes roots, twigs, and leaves, practically increases soil mass. Therefore, vegetation growth increases the risk of landslides (Mao et al, 2012*)* and (Bordoloi et al, 2020). Moreover, the depth of roots can affect the critical shear stress or facilitate slope failure on the riverbank (Gasser, et al, 2020).

This study focuses on the risk of cliff collapse due to the growth of bamboo plants along the river. The bamboo grows with various species, develops rapidly due to the dependence of the rhizome root system. Meanwhile, when not controlled, the widespread distribution of underground roots causes sprouts to grow in unwanted places. Its sustainability is due to poor maintenance or improper destruction. Bamboo is an essential part of various community activities such as building houses, traditional marriage ceremonies, and death. Furthermore, its shoots are used as local food ingredients.

The decrease in cliff stabilization on the riverbank was caused by the weight of bamboo plants (W1) and soil mass (W2). The combination of plant and soil mass is described in Figure 1. Based on this combination, this research is divided into two objectives. The first objective is to find the weight of bamboo estimated by the diameter of poles. While the secondary aim of the study is the risk of collapse. In the slope stabilization study, the mass failure was assessed based on the value of safety factors, which indicates cliff collapse when greater than 1.25 (WSDOT, 2005).

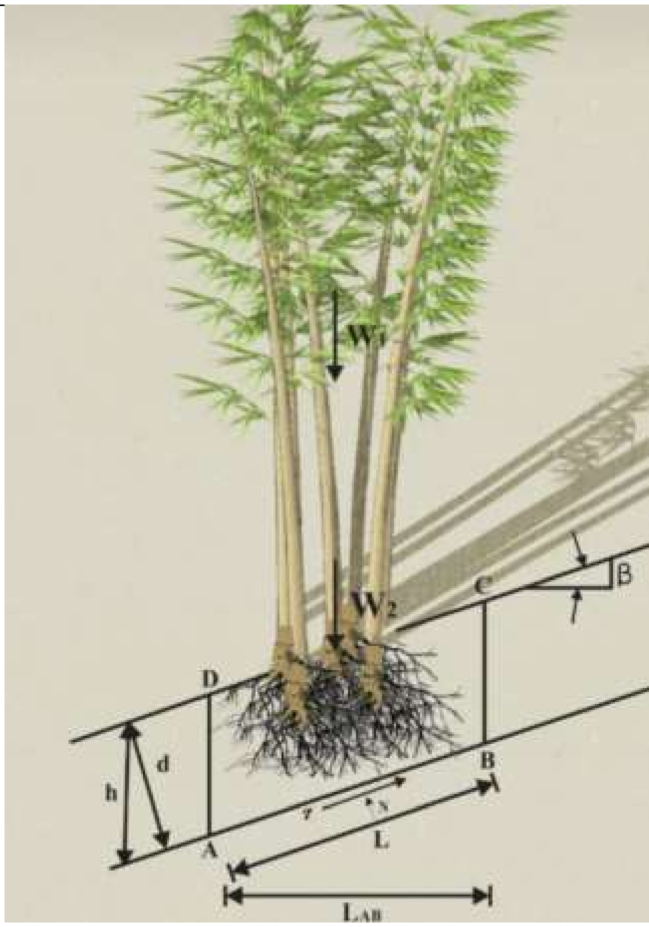

Figure 1. Description of Plant Weight on Cliff Stability.

METHODS

Study Area

The location of this study was the Walanae watershed which intersects the administrative area of Soppeng Regency. The Walanae River, as the focus of this study, has a watershed area of 740 km^2 and a length of 250 km, which flows from south to north towards the Lake Tempe alluvial.

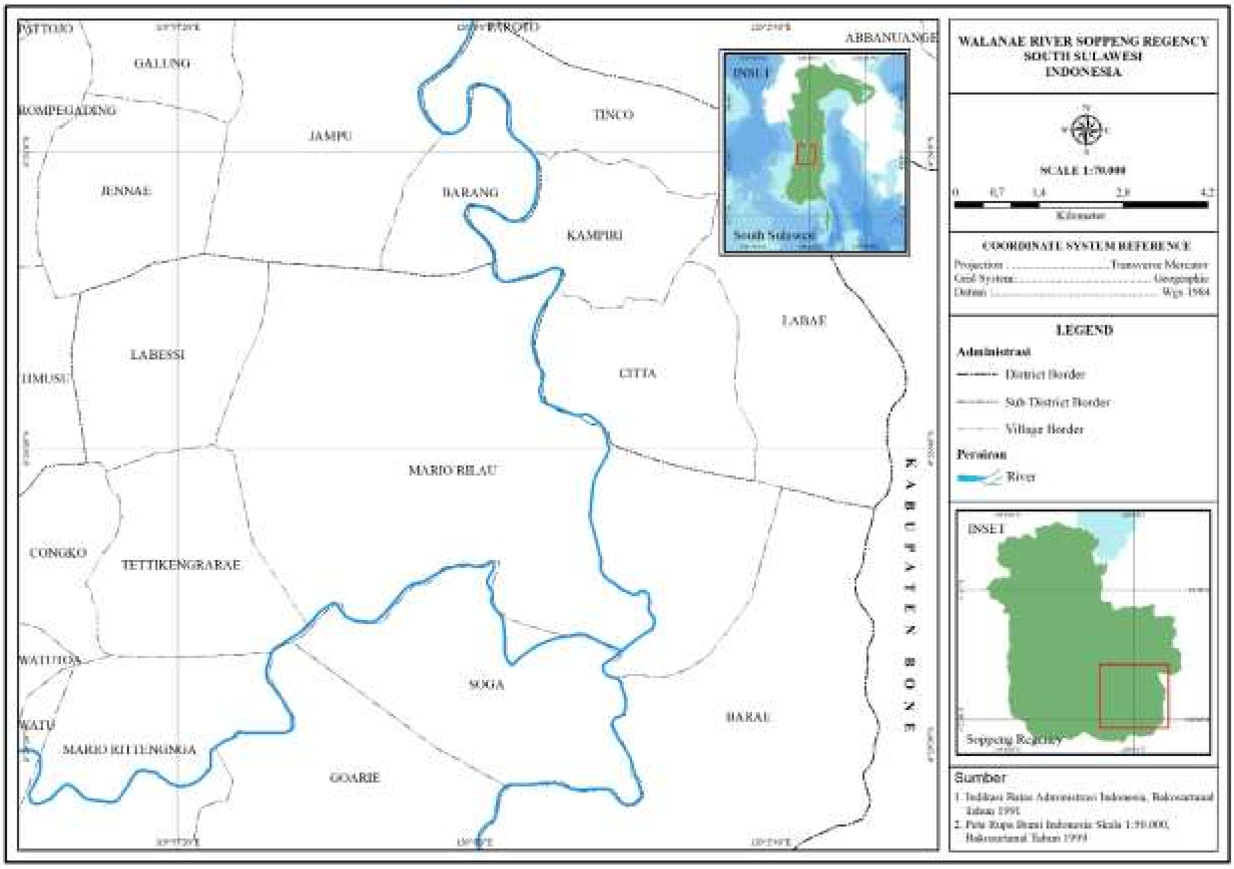

Figure 2. Field Site of Walanae River.

Sampling Procedure

Measurement of bamboo characteristics was carried out in January 2020 - March 2020. The middle area of the Walanae River was chosen as the sampling location with a river length of 42.4 km. There were 46 clumps of *Parring Bamboo* (*Gigantochloa Atter)* that became the research sample. As one of the endemic species in Indonesia, bamboo grows in the riverbank of the Walanae River. Figure 3 describes the measurement of pole diameter. It started with the determination of observation points (Figure 3a). Furthermore, Figure.3b shows the point in the stem height of 150 cm ± 5 cm (Yuen et al, T. 2017). Figure3c shows the measurement of pole diameter using a caliper.

Figure 3. The Measurement of Pole Diameter.

The average value of bamboo diameter forms the basis for calculating the total plant weight using the above-ground biomass equation. Furthermore, the calculation of the importance of bamboo-based on the pole diameter using the AGB (Above Ground Biomass) equation (Eq.1). (Yuen el al, 2017).

$$AGB = 0.269 \times D^{2.017} \quad \text{(Eq.1)}$$

The weight of the bamboo clump is calculated by the sum of all pole weights in one cluster. Next, the researchers grouped bamboo into three groups, namely Psmall, Pmed, and Plarge. The bamboo weight dataset is arranged from the smallest value to the most significant value. The data structure is divided into three categories. From the results, three types of bamboo were obtained, namely small, medium and large bamboo, based on their weight category.

The target of research is to describe the incidence of slope landslides by the additional load due to the weight of the bamboo plant. The safety factor (Fs) becomes a marker of the incident. Slope stability analysis used the ratio of shearing resistance to force (Mao et al, 2012) and (Bordoloi et al, 2020). The numerical test of slope stability using secondary data on soil properties in Soppeng Regency is shown in Table 1. The simulation of the safety factor calculation based on the angle of the slope and size of the bamboo led to the risk of riverbank sliding, and a value greater than 1.25 indicates cliff collapse [19].

$$Fs = \frac{S}{\tau} = \frac{\left(C' + Cs\right)L + (W_s' + Wt)\cos\ \beta \tan\ \theta'}{(Ws + Wc)\ sin\ \beta} \quad (2)$$

The determination of the input values is presented in the table below.

Table 1. Source of Secondary Data.

Variables	Unit	Value	Source
c' (cohesion soil effective)	kPa	14.7	Soil testing data in Walanae River (2018) using ASTM D3080
cs (apparent cohesion due to root)	kPa	7.2	Well developed grass cover condition[21][22]
L (bamboo root depth)	m	0.3	
W’s (unit weight of soil minus buoyancy)	kN/m^2	Equation $(\partial s - \partial w)h$ ∂s = 13.83 kN/m3 ∂w = 9.8 kN/m3	∂s from soil testing data in Walanae River (2018) using ASTM D854 - 14
W's (unit weight of soil)	kN/m^2	Equation $(\partial s\ )h$	
B (slope)	o	simulation	
Ø' (friction angle)	o	34.83	Soil testing data in Walanae River (2018) using ASTM D3080

RESULTS

Characteristics of Bamboo Vegetation In Riparian

Bamboo plants were discovered along the Walanae River. The results of this study showed that most of the bamboo plants were the result of 3-5years. Due to its very intensive use, bamboo is a commodity with a high selling value. The bamboo is used as building materials for traditional houses for community, local formal events, or other purposes. People tend to choose riverbanks for planting bamboo because their crops are easily transported to different locations via rivers. In addition, this plant has resistance to standing water due to flooding. Therefore, it is considered suitable for planting in riparian areas.

The calculation of pole diameter, number of poles in each clump and plant weight, and the group are presented in Table 2.

Table 2. Characteristic of The Bamboo

Characteristic		Maximum	Minimum
Number of poles in one culm		16	27
Diameter pole (cm)		0.4	6.3
Weight of bamboo (kg)		35.514	98.946
	Psmall	35.514	55.393
The weight of bamboo (kg)	Pmed	57.468	74.805
	Plarge	79.210	98.946

Table 2 shows that the maximum number of stems in one clump varies from 16 to 24 poles. The largest diameter 6.3 cm, and the smallest is 0.4 mm, then the weight of bamboo in one clump is between 35.514 kg and 98.946 kg. Three groups categorize bamboo, namely Psmall, Pmed, and Plarge. The weight of bamboo in a small category between 35.514 kg and 55.393 kg. Moreover, the weight of medium bamboo (Pmed) is between 57.468 kg and 74.805 kg. The Plarge weights between 79.210 kg and 98.946 kg.

Table 3 Show the number of poles (NP), weight, the largest pole diameter (DPmax), and the minor pole diameter (DPmin).

Table 3. The Weight and Diameter of Small Bamboo.

No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	17	35.514	0.6	4.8
2	16	38.649	0.6	4.8
3	16	39.397	0.8	4.8
4	16	42.276	0.8	5.4
5	16	42.528	0.5	5.2
6	19	43.637	0.6	4.5
7	19	44.333	0.6	4.6
8	19	45.586	0.8	4.8
9	18	47.804	0.4	4.8
10	19	47.939	0.6	4.7
11	23	47.997	0.4	4.7
12	21	48.083	0.7	4.5
13	18	49.122	0.8	4.8
14	23	49.633	0.4	4.7
15	21	50.598	0.4	4.8
16	24	50.853	0.4	4.2
17	18	52.317	0.4	5.5
18	20	52.560	0.8	5.5
19	18	55.393	0.4	5.8

Weight Average = 46.538 kg

The Weight and Diameter of Medium Bamboo.

No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	24	57.468	0.8	5.5
2	24	57.617	0.8	4.8
3	19	57.826	1.1	5.2
4	16	58.382	0.8	6.4
5	24	58.638	0.9	5.8
6	24	59.050	1.0	4.8
7	16	59.066	1.2	6.2
8	17	59.235	0.4	5.8
9	24	59.388	0.5	4.8
10	24	61.306	0.6	5.3
11	24	61.323	1.2	4.8

Continued on next page

No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
13	20	61.405	1.3	6.2
14	24	62.689	0.6	5.3
15	19	66.157	0.6	5.8
16	21	71.558	0.7	5.2
17	25	71.695	0.6	5.3
18	27	72.717	0.8	5.2
19	24	73.753	0.6	5.5
20	24	74.805	0.8	5.7

Weight Average = 63.271 kg

The Weight and Diameter of Large Bamboo

No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	23	79.210	0.6	5.5
2	23	80.222	0.8	5.5
3	24	80.584	0.6	5.9
4	24	87.093	0.6	5.5
5	20	88.620	0.8	6.3
6	19	93.404	2.1	6.3
7	20	98.946	1.3	6.3

Weight Average = 88.869 kg

The number of bamboo samples in the Psmall group was 19 clumps with an average weight of 46.538 kg. While Pmed showed an average weight of 63.271 kg from 20 poles, there were only seven clumps in the Plarge group with an average weight of 88.689 kg.

Slope Stability Analysis

Slope stability is an essential factor in riverbank protection. Meanwhile, vegetation existence on riverbanks is also one of the factors that reduce slope stability. Therefore, the greater the soil mass, the higher the potential of increasing the risk of landslides. This was exacerbated by the addition of vegetation mass which increases along with growth. Furthermore, the estimated weight, which refers to the diameter of the constituent rods, was proven to affect the risk of landslides. Therefore, the value of the safety factor is an indicator of the level of slope stability.

The results of the safety factor analysis on three bamboo groups with various slopes are presented in Figure 4.

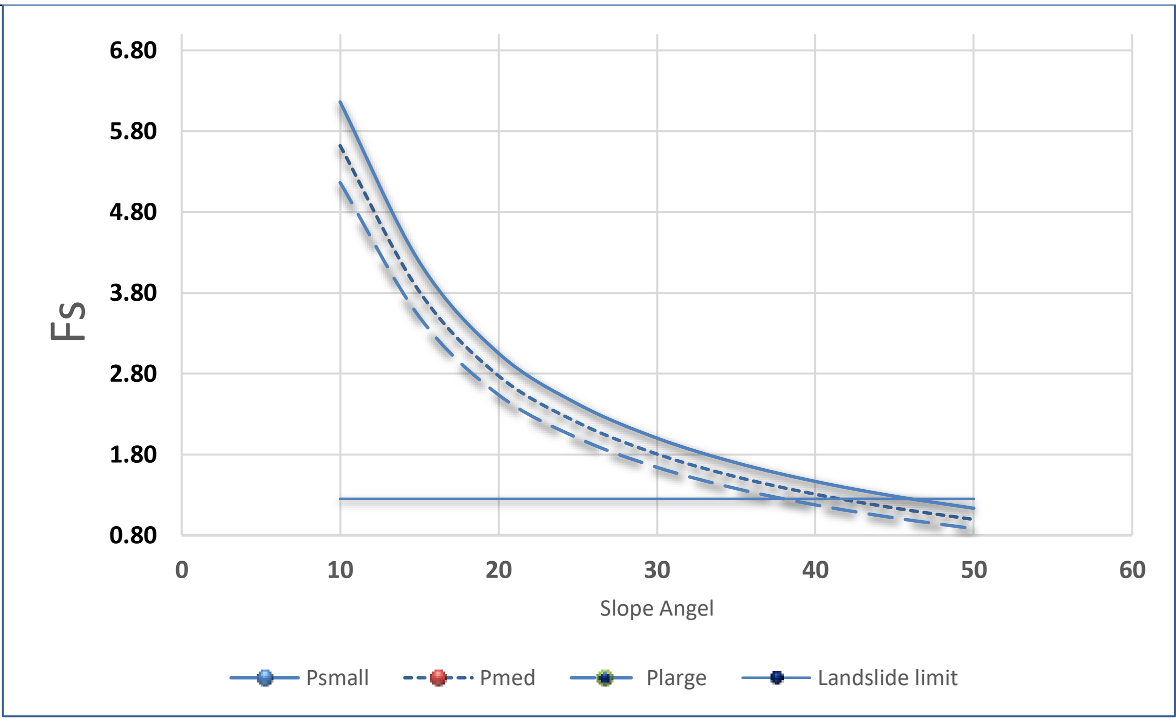

Figure 4. Estimated Safety Factor Due to the Weight of Bamboo.

Figure 4 shows the decrease of the safety factor value due to an increase in the slope angle. It proves that the larger the slope angle caused, the more extensive the risk of collapse. Psmall gives the most significant Fs value or indicates a small landslide risk in the bamboo with an average weight of 46.538 kg. If the growth of bamboo reaches a greater condition, then the chance of landslides is also greater. The increase in the number of bamboo sticks with a large diameter is a sign of an increased risk of landslides.

At a slope angle of 40°, the presence of Plarge bamboo causes landslides. Even the worse conditions occur at 45° and 50° angles, and bamboo vegetation causes sliding in the riverbank. This indicates that the slope angle of 40° is not feasible to use bamboo as reinforcement for the cliff.

DISCUSSION

Riverbanks that are equipped with riparian ecosystems contribute to the physical quality of the river. This premise was supported by the Hubble study (Hubble et al, 2010). Which stated that plant roots contribute to the reduced risk of landslides due to root strengthening. Therefore, the riparian root system was effective in increasing slope stability. Furthermore, the growth of riparian vegetation usually acts as a floodplain that can maintain the quality of the river. The presence of vegetation minimizes sedimentation as a series of erosion events. As a result, the river bed topography was better preserved and maintained river capacity (Lin et al, 2011) and (Hubble et al, 2010).

Bamboo plants on the riverbank can function as erosion protection. This study has proven that the presence of bamboo can increase the value of the safety factor. The extensive root cohesion causes an increase in soil particle bonding. As a result, the value of a security is even greater. However, the growth or addition bamboo pole causes decrease the safety factor of land. The discoveries of this study practically provided a guide for nonstructural river management methods where bamboo vegetation is one of the right choices.

Bamboo, with its distinctive morphology made of several polishes, is relatively easy to manage. The harvesting or releasing of some of its parts is an effort that can maintain the weight of the bamboo plant. Harvesting of *Parring Bamboo* at the research location is closely related to the local wisdom of the community. This bamboo is used as a traditional building material and the primary material in local traditional processions. Therefore, *Parring Bamboo* is very important for local people's lives. The habit of using bamboo supports soil bioengineering techniques in the Walanae watershed.

This study also proposes the protection of the ground surface to maintain the slope. The safety of surface erosion on riverbanks is an effort to maintain the ground-level slope. Surface erosion or the release of the soil surface due to water flow can be reduced by various methods. Litter covering treatment can improve soil erosion resistance. The litter layer is very influential in the magnitude of the kinetic energy of rain on the soil surface. Without a surface cover, raindrops can hit the soil surface and cause the surface layer to be released.(Wang et al, 2020). Mechanically, this process takes place continuously and causes an increase in the slope of the slope. Bamboo plants can protect the soil surface from the direct hit of raindrops. Several studies have shown that the thickness of litter layer in the forests regarding weathering of bamboo leaves (Seitz *et al.*, 2015) and (Hairiah, et al, 2006). Bamboo vegetation with thin and small leaves with a pointed shape and the texture like paper is easy to fall off. The release of leaves from the stems causes accumulation on the soil surface and influences the thickness of the litter layer (Nath et al, 2011). The idea is to the strengthen reason that the bamboo plant system can also prevent the increase in slopes on riverbanks.

Bamboo weight management and cliff erosion protection also prevent toe erosion from occurring, the base of a slope. (Shu et.al, 2019) described that the collapse rate of riverbanks has a positive correlation with flow velocity, water depth, and soil bearing capacity. Figure 5 illustrates the process of toe erosion and cliff collapse. The frictional force of water flow in the foot of cliff trigger the erosion process began with the peeling soil. Figure 5(ii) shows that the presence of bamboo caused the additional weight of soil that is the way the roots of the plants could not carry them. This implies that the significant weight as a burden at the foot of the cliff triggered the collapse. As a result, cliffs collapse, and the vegetation on the riverbanks will also be released.

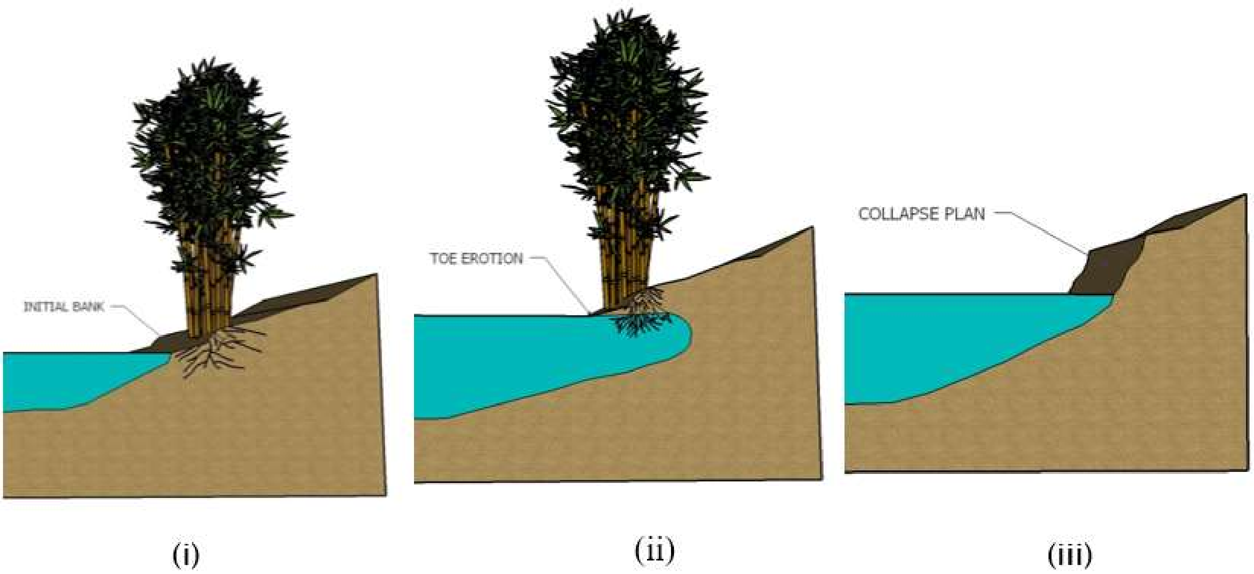

Figure 5. The Mechanism of Cliff Collapse on the Riverbank.

Soil bioengineering is feasible to be implemented as a riverbank protection technique. Since as the long the community maintains the growth of bamboo and the slope of riverbank. The sustainability of the *Parring Bamboo* vegetation at Walanae Watershed contributes to ecological protection. It prevents the degradation of land and water resources.

CONCLUSION

Based on the results obtained and numerical analysis of riverbank silty, the authors conclude that the bamboo vegetation on the Walanae riverbanks is divided into three categories based on the weight of clumps. The small category has an average weight of 46.538 kg. The medium type has an average weight of 63.271 kg, and the large bamboo weighing is 88.869 kg. The increase in weight was caused by the addition of the number of stems.

The numerical analysis results indicate that the presence of bamboo vegetation increases the risk of cliff landslides. Therefore, as its weight increases, it contributes to a decrease in the value of the safety factor. The application of bamboo vegetation as slope protection is not possible in slope angles more than 40°. The soil bioengineering technique with bamboo vegetation on riverbanks should consider the reduction in the number of polishes in each clump. Harvesting activities are the solution for this technique.

ACKNOWLEDGEMENTS

The authors express gratitude for the contribution of funds through the financing scheme "Acceleration of Professors through the Institute for Research and Community Service, Universitas Negeri Makassar Year of 2020".

REFERENCES

1. Abernethy B. and Rutherfurd I.D. 2000. "Does the weight of riparian trees destabilize riverbanks?," *Regul. Rivers Res. Manag. An Int. J. Devoted to River Res. Manag.*, vol. 16, no. 6, pp. 565–576.
2. Bischetti G.B., De Cesare G., Mickovski S.B., Rauch H.P., Schwarz M., and Stangl R. 2021. "Design and temporal issues in Soil Bioengineering structures for the stabilisation of shallow soil movements," *Ecol. Eng.*, vol. 169, p. 106309.
3. Bordoloi S., and Ng. C.W.W. 2020. "The effects of vegetation traits and their stability functions in bio-engineered slopes: A perspective review," *Eng. Geol.*, p. 105742.
4. Cislaghi A. E., Chiaradia A., and Bischetti G.B. 2017. "Including root reinforcement variability in a probabilistic 3D stability model," *Earth Surf. Process. Landforms*, vol. 42, no. 12, pp. 1789–1806.
5. Cislaghi A. E., Chiaradia A., and Bischetti G.B. 2018. "A probabilistic multidimensional approach to quantify large wood recruitment from hillslopes in mountainous-forested catchments," *Geomorphology*, vol. 306, pp. 108–127.
6. De Baets S., Torri D., Poesen J., Salvador M.P., and Meersmans J.. 2008. "Modelling increased soil cohesion due to roots with EUROSEM," *Earth Surf. Process. Landforms J. Br. Geomorphol. Res. Gr.*, vol. 33, no. 13, pp. 1948–1963.
7. Dietrich W.E., McKean J., Bellugi D., and Perron T. 2007. "The prediction of shallow landslide location and size using a multidimensional landslide analysis in a digital terrain model," in *In: Chen, CL; Major, JJ, editors. Proceedings of the Fourth International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment (DFHM-4); Chengdu, China, September 10-13, 2007. The*

Netherlands, Amsterdam: IOS Press. 12 p.

8. Gasser E. *et al.*. 2019. "A review of modeling the effects of vegetation on large wood recruitment processes in mountain catchments," *Earth-Science Rev.*, vol. 194, pp. 350–373.
9. Gasser E., Perona P., Dorren L., PhillFips C., Hübl J., and Schwarz M. 2020. "A new framework to model hydraulic bank erosion considering the effects of roots," *Water*, vol. 12, no. 3, p. 893.
10. Guo W.Z. *et al.*. 2020. "Telling a different story: The promote role of vegetation in the initiation of shallow landslides during rainfall on the Chinese Loess Plateau," *Geomorphology*, vol. 350, p. 106879.
11. Hairiah, H. Sulistyani, Suprayogo D., Purnomosidhi P., Widodo R.H., and Van Noordwijk M. 2006. "Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung," *For. Ecol. Manage.*, vol. 224, no. 1–2, pp. 45–57.
12. Lin C., Yang Y., Guo J., Chen G., and Xie J. 2011. "Fine root decomposition of evergreen broadleaved and coniferous tree species in mid-subtropical China: dynamics of dry mass, nutrient and organic fractions," *Plant Soil*, vol. 338, no. 1–2, pp. 311–327.
13. Lu C., Chen S., Jiang Y., Shi J., Yao C., and Su X. 2018. "Quantitative analysis of riverbank groundwater flow for the Qinhuai River, China, and its influence factors," *Hydrol. Process.*, vol. 32, no. 17, pp. 2734–2747.
14. McMahon J.M. *et al.*. 2020. "Vegetation and longitudinal coarse sediment connectivity affect the ability of ecosystem restoration to reduce riverbank erosion and turbidity in drinking water," *Sci. Total Environ.*, vol. 707, p. 135904.
15. Mao Z. *et al.*. 2012. "Engineering ecological protection against landslides in diverse mountain forests: choosing cohesion models," *Ecol. Eng.*, vol. 45, pp. 55–69.
16. Nath A.J. and Das A.K. 2011. "Decomposition dynamics of three priority bamboo species of homegardens in Barak Valley, Northeast India," *Trop. Ecol.*, vol. 52, no. 3, pp. 325–330.
17. Pollen N. and Simon A. 2005. "Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model," *Water Resour. Res.*, vol. 41, no. 7.
18. Recking A., Piton A., Montabonnet L., Posi S., and Evette A. 2019. "Design of fascines for riverbank protection in alpine rivers: Insight from flume experiments," *Ecol. Eng.*, vol. 138, pp. 323–333
19. Rey F. *et al.*. 2019. "Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration," *Sci. Total Environ.*, vol. 648, pp. 1210–1218.
20. Schmitt K., Schäffer M., Koop J., and Symmank . 2018. "River bank stabilisation by bioengineering: potentials for ecological diversity," *J. Appl. Water Eng. Res.*, vol. 6, no. 4, pp. 262–273.
21. Shen P., Zhang L.M., Chen H.X., and Gao L. 2017. "Role of vegetation restoration in mitigating hillslope erosion and debris flows," *Eng. Geol.*, vol. 216, pp. 122–133.
22. Seitz S. *et al.*. 2015. "The influence of leaf litter diversity and soil fauna on initial soil erosion in subtropical forests," *Earth Surf. Process. Landforms*, vol. 40, no. 11, pp. 1439–1447.
23. Shu A., Duan G., Rubinato M., Tian L., Wang M., and Wang S.. 2019. "An experimental study on mechanisms for sediment transformation due to riverbank collapse," *Water*, vol. 11, no. 3, p. 529.
24. Wang L., Zhang G., Zhu P., and Wang X. 2020. "Comparison of the effects of litter covering and incorporation on infiltration and soil erosion under simulated rainfall," *Hydrol. Process.*, vol. 34, no. 13, pp. 2911–2922.
25. WSDOT. 2005. "Geotechnical design manual M46-03." Washington State Department of Transportation Olympia, WA.
26. Wu T.H. and Watson A. 1998. "In situ shear tests of soil blocks with roots," *Can. Geotech. J.*, vol. 35, no. 4, pp. 579–590.
27. Yuen J.Q., Fung T., and Ziegler A.D. 2017. "Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties," *For. Ecol. Manage.*, vol. 393, pp. 113–138.
28. Zhang H., Zhao Z., Ma G., and Sun L. 2020. "Quantitative evaluation of soil anti-erodibility in riverbank slope remediated with nature-based soil bioengineering in Liaohe River, Northeast China," *Ecol. Eng.*, vol. 151, p. 105840.

Cover Letter

Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Nurlita Pertiwi› Bakhrani Rauf, and Mithen Lullulangi

No	Reviewer Comment	Revision	Position
1	the bond between the roots and the soil" to "the roots	the bond between the roots to the soil	Abstract
2	river bank" I should use the same term for this physical mechanism. I should always use "riverbank".	causes riverbank sliding	
3	river bank sliding" Could the authors better describe this failure	However, an increase in plant weight due to its growth causes additional loads of soil. The condition triggers the release of soil on the slopes and causes riverbank sliding.	
4	middle area" Where?	middle area of Walanae watershed	
5	46 clumps" How did the authors select them? Which is the discriminant factor?	The researchers selected 46 clumps of *Parring Bamboo* (*Gigantochloa Atter*) as an endemic bamboo in this area and growing in the riverbank	
6	river reinforcement" What does it mean?	The research results bamboo is feasible to be applied to riverbank protection using the soil bioengineering method	

No	Reviewer Comment	Revision	Position
1	The authors did not mention the term "soil bio-engineering". I think that it is a great forgetfulness (Bischetti et al., 2021, 2014; Rey et al., 2019)	An explanation of the concept of soil biuengineering by adopting the results of the study by Bischetti et al., 2021; Rey et al., 2019)	Introduction
2	The authors neglected some interesting works that summarises the state-of-the-art on the topic of streambank stability (Gasser et al., 2020, 2019)	The ability of plants to maintain streambank conditions depends on the depth of their roots. While, ……. stresses due to river flow [Gasser, 2019)	
3	Line 32: "degradation" What does it mean? Please, explain.	However, an increase in plant weight due to its growth causes additional loads of soil. The condition triggers the release of soil on the slopes and causes riverbank sliding.	
4	Line 39: "2018" to "2018)"	Removed	
5	Line 40: "50 years...". This sentence should be moved to "Study site".	Removed	
6	Line 46: "both ecological and mechanical" What does it mean? Please, explain.	Removed	
7	Line 46: "purifying" What does it mean? Please, explain. References?	Removed	
8	Line 69: "in Indonesia" Here, it is not necessary to dealt with the study area.	Removed	
9	Please, clarify which is the main objective and the secondary ones (maybe using a list).	Based on this combination, this research is divided into two objectives. The first objective is to find the weight of bamboo estimated by the ….. when greater than 1.25 [18].	

No	Reviewer Comment	Revision	Position
1	"Research locations" to "Study area".	Study Area	Materials and Method
2	km2" Please, make attention on space and apex.	km^2	
3	Figure 2: The figure is of poor quality, not so readable.	Increasing the image resolution	
4	Line 94: Why in italic?	sentences written with narration	
5	Table 1: It is not useful reporting the specific coordinates. Maybe, it is better to draw a map with the river and the samples sites.	the table that writes the coordinates is discarded	
6	Figure 3: Maybe, I should replace it with a real photo.	Replaced with real photos and added explanations	
7	Line 46: "purifying" What does it mean? Please, explain. References?	Removed	
8	Line 69: "in Indonesia" Here, it is not necessary to dealt with the study area.	Removed	
9	Line 107: The equation is unreadable.	Enlarged font	
10	line 116: Why did the authors not use the 2.5D or 3D stability models (Chiaradia et al., 2016; Cislaghi et al., 2018, 2017; Dietrich et al., 2007)	The author only compare the load and shear strength	

No	Reviewer Comment	Revision	Position
12	Line 117: The equation is unreadable.	Enlarged font	Materials and Method
13	Table 2: Did the authors take all data from the literature? Please, explain the measurements (for soil cohesion, the soil weight, etc.). Why did they use "7.2 kPa" for the root reinforcement?	The author adds measurement standards	
14	remove the reference to technical report (Baharuddin and Malamassam)	The references were replaced with Yuen et.al 2017	

No	Reviewer Comment	Revision	Position
1	Figure 4: Which is its utility?	Removed	Results
2	km2" Please, make attention on space and apex.	km^2	
3	Tables 3-4: They are not useful to the take-home-message of the paper.	Replaced with table 2 and table 3	
4	Table 5: Including min, max and mean.		
5	Figure 5: The figure could be improved.		
6	Figure 3: Maybe, I should replace it with a real photo.	Replaced with real photos and added explanations	
7	"the greater the soil mass". What does it mean?	The meaning is clear	
8	Figure 7: The figure is of very poor quality. The distances among points are undetectable. I should insert a horizontal line at FS=1. Are there some points below this line?	repaired according to instructions	

No	Reviewer Comment	Revision	Position
1	The discussion is very general. I think that the mechanisms could be discussed before. A comparison with similar works of the literature is missing.	The author clarifies the discussion by adding references	Discussion

No	Reviewer Comment	Revision	Position
1	avoid the bullets list in the conclusions.	The author makes conclusions in the form of paragraphs	Conclusion

No	Reviewer Comment	Revision	Position
1	Please, remove the reference to technical report (Baharuddin and Malamassam, 2013; Chan et al. 2019; Liang et al. 2019; Vargas Luna 2016)	Removed the references	References
2	Recoemded references	Reference cited	

UNM

Nurlita UNM <nurlita.pertiwi@unm.ac.id>

Decision on manuscript JEENG-02554-2021-01

2 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 18 Agustus 2021 17.11
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: Nurlita Pertiwi <nurlita.pertiwi@unm.ac.id>

August 18, 2021
JEENG-02554-2021-01
Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Dear Dr. Nurlita Pertiwi,

I am pleased to inform you that your manuscript, entitled: Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia, might be accepted for publication in our journal, pending some minor changes suggested by reviewers (see below).

Please revise your paper strictly according to the attached Reviewers comments. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Your manuscript has been analyzed by a web-based anti-plagiarism system (iThenticate).
Please note that this email may not include all details of your article's evaluation. The full decision and file attachments are available here:
https://www.editorialsystem.com/jeeng/article/258613/view/#showDecisionLetter255715

Editor has attached the file to this decision.

Attachment:

- https://www.editorialsystem.com/dl/df/6601/5ff86d221d159f0937416a5cbac97a70/ (Editor)

Nurlita UNM <nurlita.pertiwi@unm.ac.id> 19 Agu 2021 15.31

Kepada: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>

Dear publisher.

I want to inform about the revision of article has been submit on the journal system. I also send it in the attachment.

King regards

Nurlita Pertiwi

REV JEENG-02554-2021-01
915 KB

Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Nurlita Pertiwi[1],* Bakhrani Rauf[2], and Mithen Lullulangi[3]
[1,2,3,] Civil engineering Education Faculty of Engineering, Universitas Negeri Makassar, Makassar, Indonesia
* **Correspondence:** Email: nurlita.pertiwi@unm.ac.id.

ABSTRACT
Bamboo vegetation is an endemic plant in Indonesia that grows on riverbanks. These plants have the potential to increase shear resistance due to the bond between the roots to the soil. However, an increase in plant weight due to its growth causes additional loads of soil. The condition triggers the release of soil on the slopes and causes riverbank sliding. Therefore, in developing the riparian ecological function, it is necessary to maintain the plants without neglecting the risk of physical damage to the river. This study ~~aims~~ aimed to estimate the risk of riverbank sliding due to the presence of bamboo plants by utilizing the bamboo vegetation conditions on the Walanae River. ~~This~~ It was carried out on the 42.4 km riverbank in the middle area of Walanae watershed. The researchers selected 46 clumps of *Parring Bamboo* (*Gigantochloa Atter*) as an endemic bamboo in this area and growing in the riverbank. The diameter of the bamboo trunk is the basis for an estimate of the weight of the bamboo clump. Furthermore, a numerical analysis was carried out by taking into account the load and shear resistance on the slope, including the weight of the plant. The research results indicated that bamboo is feasible to be applied ~~to~~ for riverbank protection using the soil bioengineering method. The bamboo weight, which is indicated by the number of poles and diameter, significantly affects the stability of the slope. Therefore, the prevention of rising weight by harvesting method is critical to consider in riverbank protection.

Keywords: slope, diameter, weight of bamboo, Walanae

INTRODUCTION

As an ecological sub-system, riverbanks are very vulnerable to degradation due to their internal characteristics combination and flow dynamics (McMahon *et al.*, 2020). Environmental restoration of the river system is one of the ecological protection options by combining the flow and soil characteristics (Rey et al., 2019). Moreover, the high sedimentation and slides are evidence of the decreasing of the riverbank quality. Internally, it is characterized by soil, vegetation, and aquatic conditions of the river.

In contrast, the river flow dynamics are caused by high rainfall, floods, and sediment transport leads to erosion and riverbank collapse (Recking et al., 2019) . Meanwhile, the function of the riverbank as a regulator of river flow depends on its maintenance (Lu et al., 2018). Ecologically, the river bank also acts as a riparian and is a transition zone in the aquatic zone, always wet with a terrestrial area that sometimes experiences wet or dry conditions (Schmitt, et al., 2018).

The existence of vegetation on the banks of the river dramatically affects the physical processes of natural channels. The growth of plants ~~make the contribution~~contributes to ~~for~~ riverbank stabilization.~~ ~~ (Bischetti, et al., 2014). However, the process of protecting slopes and their stability and their relationship to plants has not been a serious concern. The presence of large trees increases the potential for slope movement. ~~-~~Moreover, the dynamics of plant growth are very influential on the success of cliff protection (Cislaghi, et al., 2018). ~~-~~Therefore, temporal plant growth should be an essential consideration in soil bioengineering. The dynamics of root reinforcement are exciting studies in applying environmentally friendly cliff protection (Bischetti, et al., 2021).

The plant system that includes root, stem, and leaf has a contribution to the bank stability. This contribution can change in line with the characteristics of the stand and the nature of groundwater retention. The stem and leaf system can minimize splash erosion and reduce the risk of scouring the soil. Furthermore, the root system with its growth dynamics has raised many questions about the potential of roots towards soil stability. Root growth contributes to soil shear resistance (Cislaghi, et al., 2017).

The ability of plants to maintain streambank conditions depends on the depth of their roots.~~ While, t~~The natural mechanism that occurs in vegetation can technically be related to the theory of channel hydraulics. The streambank resistance or cliff reinforcement is better with the presence of plant root networks. Plant roots that coincide with the soil shear plane cause a good interaction with soil reinforcement. On the other hand, channel roughness increases along with plant roots~~ increase the channel roughness increase~~. This condition causes a loss of energy in the flow and reduces the flow velocity. With these two mechanisms, plants strengthen riverbanks internally and externally. Plant roots also reduce external stresses due to river flow (Gasser *et al.*, 2019). .

The riverbank root systems also improve stability and maintain geometric bank conditions ~~-~~(Abernethy et al., 2000). The strengthening mechanism of the cliffs with the presence of plant roots is their ability to act as anchors on the ground. Therefore, they are able to support the riverbank soil mass; moreover, and the vegetation roots produce a more robust soil matrix and increase its stability against the risk of collapse (Wu et al., 1998). Although the hydrodynamic model of river flow is influenced by riverbank vegetation, this plant spreads the flow pattern in other to reduce speed. As a result, there is a kinetic energy decrease in soil mass, which reduces the risk of its release on riverbanks (Pollen et al., 2005).

The contradictory opinions about the role of plant roots on soil stability describe that: the dynamics of plants and their growth cause an increase in the risk of cliff slides (Cislaghi, et al., 2018). The increase in lateral strength due to root growth is also an interesting consideration in the study of soil bioengineering (Dietrich, et al., 2007). Another study, ~~-~~also described the potential for decreasing soil stability due to riparian plant root systems (Zhang, et ~~al~~al., 2020). ~~-~~The intrinsic properties of the soil or its properties affect the erosion potential of the soil. However, the growth of the root system and the accumulation of litter can change the nature and structure of the soil, which can increase the potential for cliff erosion.

Plant growth is also considered a problem at the risk of rock slides. The interaction between water flow and vegetation on the riverbank was also analyzed with a mechanical approach. The increasing shear forces due to plant growth lead to a rise in the safety factor value at a certain slope. Furthermore, plant growth, which includes roots, twigs, and leaves, practically increases soil mass. Therefore, vegetation growth increases the risk of landslides (Mao et al., 2012*)* and (Bordoloi et al., 2020). Moreover, the depth of roots can affect the critical shear stress or facilitate slope failure on the riverbank (Gasser, et al., 2020).

This study ~~focuses~~ focused on the risk of cliff collapse due to the growth of bamboo plants along the river. The bamboo grows with various species and~~,~~ develops rapidly due to the dependence of the rhizome root system. Meanwhile, when not controlled, the widespread distribution of underground roots causes sprouts to grow in unwanted places. Its sustainability is due to poor maintenance or improper destruction. Bamboo is an essential part of various community activities such as building houses, traditional marriage ceremonies, and death. Furthermore, its shoots are used as local food ingredients.

The decrease in cliff stabilization on the riverbank was caused by the weight of bamboo plants (W1) and soil mass

Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Commented [A1]: In order?
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)
Formatted: English (United States)

(W2). The combination of plant and soil mass is described in Figure 1. ~~Based~~ On the basis of ~~on~~ this combination, this research ~~is~~ was divided into two objectives. The first objective ~~is~~ was to find the weight of bamboo estimated by the diameter of poles.~~ While t~~The secondary aim of the study is the risk of collapse. In the slope stabilization study, the mass failure was assessed based on the value of safety factors, which indicates cliff collapse when greater than 1.25 (WSDOT, 2005).

Figure 1. Description of Plant Weight on Cliff Stability.

METHODS

Study Area

The location of this study was the Walanae watershed which intersects the administrative area of Soppeng Regency. The Walanae River, as the focus of this study, has a watershed area of 740 km^2 and a length of 250 km, which flows from south to north towards the Lake Tempe alluvial.

Figure 2. Field Site of Walanae River.

Sampling Procedure

The ~~M~~measurement of bamboo characteristics was carried out in January 2020 - March 2020. The middle area of the Walanae River was chosen as the sampling location with a river length of 42.4 km. There were 46 clumps of *Parring Bamboo* (*Gigantochloa Atter)* that became the research sample. As one of the endemic species in Indonesia, bamboo grows in the riverbank of the Walanae River. Figure 3 describes the measurement of pole diameter. It started with the determination of observation points (Figure 3a). Furthermore, Figure.3b shows the point in the stem height of 150 cm ± 5 cm (Yuen et al., T. 2017). Figure 3c shows the measurement of pole diameter using a caliper.

Formatted: English (United States)

Figure 3.The Measurement of Pole Diameter.

The average value of bamboo diameter forms the basis for calculating the total plant weight using the above-ground biomass equation. Furthermore, the calculation of the importance of bamboo-based on the pole diameter using the AGB (Above Ground Biomass) equation (Eq.1). (Yuen el al., 2017).

AGB = 0.269 x D$^{2.017}$ (Eq.1)

The weight of the bamboo clump is calculated by the sum of all pole weights in one cluster. Next, the researchers grouped bamboo into three groups, namely Psmall, Pmed, and Plarge. The bamboo weight dataset is arranged from the smallest value to the most significant value. The data structure is divided into three categories. From the results, three types of bamboo were obtained, namely small, medium and large bamboo, based on their weight category.

The target of the research ~~is~~ was to describe the incidence of slope landslides by the additional load due to the weight of the bamboo plant. The safety factor (Fs) becomes a marker of the incident. Slope stability analysis used the ratio of shearing resistance to force (Mao et al., 2012*)* and (Bordoloi et al., 2020). The numerical test of slope stability using secondary data on soil properties in Soppeng Regency is shown in Table 1. The simulation of the safety factor calculation based on the angle of the slope and size of the bamboo led to the risk of riverbank sliding, and a value greater than 1.25 indicates cliff collapse [19].

Formatted: English (United States)

$$Fs = \frac{S}{\tau} = \frac{(C' + Cs)L + (W_s' + Wt)\cos\beta \tan\theta'}{(Ws + Wc)\sin\beta} \qquad (2)$$

The determination of the input values is presented in the table below.

Table 1. Source of Secondary Data.

RESULTS

Characteristics of Bamboo Vegetation In Riparian

Bamboo plants were discovered along the Walanae River. The results of this study showed that most of the bamboo plants were the result of 3-5 years. Due to its very intensive use, bamboo is a commodity with a high selling value. The bamboo is used as building materials for traditional houses for community, local formal events, or other purposes. People tend to choose riverbanks for planting bamboo, because their crops are easily transported to different locations via rivers. In addition, this plant has resistance to standing water due to flooding. Therefore, it is considered suitable for planting in riparian areas.

The calculation of pole diameter, number of poles in each clump and plant weight, and the group are presented in Table 2.

Table 2. Characteristic of ~~The B~~bamboo

Table 2 shows that the maximum number of stems in one clump varies from 16 to 24 poles. The largest diameter is 6.3 cm, and the smallest is 0.4 mm, then the weight of bamboo in one clump is between 35.514 kg and 98.946 kg. Three groups categorize bamboo, namely Psmall, Pmed, and Plarge. The weight of bamboo in ~~a~~ the small category is between 35.514 kg and 55.393 kg. Moreover, the weight of medium bamboo (Pmed) is between 57.468 kg and 74.805 kg. ~~The~~ Plarge bamboo weights between 79.210 kg and 98.946 kg.

Table 3 Show the number of poles (NP), weight, the largest pole diameter (DPmax), and the minor pole diameter (DPmin).

Table 3. The Weight and Diameter of Small Bamboo.

The number of bamboo samples in the Psmall group was 19 clumps with an average weight of 46.538 kg. ~~While~~ In turn, Pmed showed an average weight of 63.271 kg from 20 poles, there were only seven clumps in the Plarge group with an average weight of 88.689 kg.

Slope Stability Analysis

Slope stability is an essential factor in riverbank protection. Meanwhile, vegetation existence on riverbanks is also one of the factors that reduce slope stability. Therefore, the greater the soil mass, the higher the potential of increasing the risk of landslides. This was exacerbated by the addition of vegetation mass which increases along with growth. Furthermore, the estimated weight, which refers to the diameter of the constituent rods, was proven to affect the risk of landslides. Therefore, the value of the safety factor is an indicator of the level of slope stability.

The results of the safety factor analysis on three bamboo groups with various slopes are presented in Figure 4.

Figure 4.Estimated Safety Factor Due to the Weight of Bamboo.

Figure 4 shows the decrease of the safety factor value due to an increase in the slope angle. It proves that the larger the slope angle caused, the more extensive the risk of collapse. Psmall gives the most significant Fs value or indicates a small landslide risk in the bamboo with an average weight of 46.538 kg. If the growth of bamboo reaches a greater condition, then the chance of landslides is also ~~greater~~higher. The increase in the number of bamboo sticks with a large diameter is a sign of an increased risk of landslides.

At a slope angle of 40°, the presence of Plarge bamboo causes landslides. Even ~~the~~ worse conditions occur at 45° and 50° angles, and bamboo vegetation causes sliding in the riverbank. This indicates that the slope angle of 40° is not feasible to use bamboo as reinforcement for the cliff.

DISCUSSION

The ~~R~~riverbanks that are equipped with riparian ecosystems contribute to the physical quality of the river. This premise was supported by the Hubble study (Hubble et al., 2010)~~.~~ ~~W~~which stated that plant roots contribute to the reduced risk of landslides due to root strengthening. Therefore, the riparian root system was effective in increasing slope stability. Furthermore, the growth of riparian vegetation usually acts as a floodplain that can maintain the quality of the river. The presence of vegetation minimizes sedimentation as a series of erosion events. As a result, the river bed topography was better preserved and maintained river capacity (Lin et al., 2011) and (Hubble et al., 2010).

Bamboo plants on the riverbank can function as erosion protection. This study has proven that the presence of bamboo can increase the value of the safety factor. The extensive root cohesion causes an increase in soil particle bonding. As a result, the value of a security is even greater. However, the growth or addition of bamboo pole ~~causes~~ decreases the safety factor of land. The discoveries of this study practically provided a guide for nonstructural river management methods where bamboo vegetation is one of the right choices.

Bamboo, with its distinctive morphology made of several polishes, is relatively easy to manage. The harvesting or releasing of some of its parts is an effort that can maintain the weight of the bamboo plant. Harvesting of *Parring Bamboo* at the research location is closely related to the local wisdom of the community. This bamboo is used as a traditional building material and the primary material in local traditional processions. Therefore, *Parring Bamboo* is very important for lives of local people~~'s lives~~. The habit of using bamboo supports soil bioengineering techniques in the Walanae watershed.

This study also ~~proposes~~ proposed the protection of the ground surface to maintain the slope. The safety of surface erosion on riverbanks is an effort to maintain the ground-level slope. Surface erosion or the release of the soil surface due to water flow can be reduced by various methods. Litter covering treatment can improve the soil erosion resistance. The litter layer is very influential in the magnitude of the kinetic energy of rain on the soil surface. Without a surface cover, raindrops can hit the soil surface and cause the surface layer to be released~~.~~ (Wang et al., 2020). Mechanically, this process takes place continuously and causes an increase in the slope of the slope. Bamboo plants can protect the soil surface from the direct hit of raindrops. Several studies have shown that the thickness of litter layer in the forests regarding weathering of bamboo leaves (Seitz *et al.*, 2015) and (Hairiah, et al., 2006). Bamboo vegetation with thin and small leaves with a pointed shape and the texture like paper is easy to fall off. The release of leaves from the stems causes accumulation on the soil surface and influences the thickness of the litter layer (Nath et al., 2011). The idea is to the strengthen reason that the bamboo plant system can also prevent the increase in slopes on riverbanks.

Bamboo weight management and cliff erosion protection also prevent toe erosion from occurring~~,~~ at the base of a slope. (Shu et~~.~~ al., 2019) described that the collapse rate of riverbanks has a positive correlation with flow velocity, water depth, and soil bearing capacity. Figure 5 illustrates the process of toe erosion and cliff collapse. The frictional force of water flow in the foot of cliff trigger the erosion process began with the peeling soil. Figure 5(ii)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

Formatted: English (United States)

shows that the presence of bamboo caused the additional weight of soil that is the way the roots of the plants could not carry them. This implies that the significant weight as a burden at the foot of the cliff triggered the collapse. As a result, cliffs collapse, and the vegetation on the riverbanks will also be released.

Figure 5.The Mechanism of Cliff Collapse on the Riverbank.

Soil bioengineering is feasible to be implemented as a riverbank protection technique, ~~. Since~~ as the long the community maintains the growth of bamboo and the slope of riverbank. The sustainability of the *Parring Bamboo* vegetation at Walanae Watershed contributes to ecological protection. It prevents the degradation of land and water resources.

CONCLUSIONS

Formatted: Polish

~~Based~~ On the basis of ~~on~~ the results obtained and numerical analysis of silty riverbank ~~silty~~, the authors conclude that the bamboo vegetation on the Walanae riverbanks is divided into three categories based on the weight of clumps. The small category has an average weight of 46.538 kg. The medium type has an average weight of 63.271 kg, and the large bamboo weighing is 88.869 kg. The increase in weight was caused by the addition of the number of stems.

The numerical analysis results indicate that the presence of bamboo vegetation increases the risk of cliff landslides. Therefore, as its weight increases, it contributes to a decrease in the value of the safety factor. The application of bamboo vegetation as slope protection is not possible in the slope angles ~~more~~ greater than 40°. The soil bioengineering technique with bamboo vegetation on riverbanks should consider the reduction in the number of polishes in each clump. Harvesting activities are the solution for this technique.

Acknowledgements

The authors express gratitude for the contribution of funds through the financing scheme "Acceleration of Professors through the Institute for Research and Community Service, Universitas Negeri Makassar Year of 2020".

REFERENCES

1. Abernethy B. and Rutherfurd I.D. 2000. “Does the weight of riparian trees destabilize riverbanks?,” *Regul. Rivers Res. Manag. An Int. J. Devoted to River Res. Manag.*, vol. 16, no. 6, pp. 565–576.
2. Bischetti G.B., De Cesare G., Mickovski S.B., Rauch H.P., Schwarz M., and Stangl R. 2021. “Design and temporal issues in Soil Bioengineering structures for the stabilisation of shallow soil movements,” *Ecol. Eng.*, vol. 169, p. 106309.
3. Bordoloi S., and Ng. C.W.W. 2020. “The effects of vegetation traits and their stability functions in bio-engineered slopes: A perspective review,” *Eng. Geol.*, p. 105742.
4. Cislaghi A. E., Chiaradia A., and Bischetti G.B. 2017. “Including root reinforcement variability in a probabilistic 3D stability model,” *Earth Surf. Process. Landforms*, vol. 42, no. 12, pp. 1789–1806.
5. Cislaghi A. E., Chiaradia A., and Bischetti G.B. 2018. “A probabilistic multidimensional approach to quantify large wood recruitment from hillslopes in mountainous-forested catchments,” *Geomorphology*, vol. 306, pp. 108–127.
6. De Baets S., Torri D., Poesen J., Salvador M.P., and Meersmans J.. 2008. “Modelling increased soil cohesion due to roots with EUROSEM,” *Earth Surf. Process. Landforms J. Br. Geomorphol. Res. Gr.*, vol. 33, no. 13, pp. 1948–1963.
7. Dietrich W.E., McKean J., Bellugi D., and Perron T. 2007. “The prediction of shallow landslide location and size using a multidimensional landslide analysis in a digital terrain model,” in *In: Chen, CL; Major, JJ, editors. Proceedings of the Fourth International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment (DFHM-4); Chengdu, China, September 10-13, 2007. The Netherlands, Amsterdam: IOS Press. 12 p*.
8. Gasser E. *et al.*. 2019. “A review of modeling the effects of vegetation on large wood recruitment processes in mountain catchments,” *Earth-Science Rev.*, vol. 194, pp. 350–373.
9. Gasser E., Perona P., Dorren L., PhillFips C., Hübl J., and Schwarz M. 2020. “A new framework to model hydraulic bank erosion considering the effects of roots,” *Water*, vol. 12, no. 3, p. 893.
10. Guo W.Z. *et al.*. 2020. “Telling a different story: The promote role of vegetation in the initiation of shallow landslides during rainfall on the Chinese Loess Plateau,” *Geomorphology*, vol. 350, p. 106879.
11. Hairiah, H. Sulistyani, Suprayogo D., Purnomosidhi P., Widodo R.H., and Van Noordwijk M. 2006. “Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung,” *For. Ecol. Manage.*, vol. 224, no. 1–2, pp. 45–57.
12. Lin C., Yang Y., Guo J., Chen G., and Xie J. 2011. “Fine root decomposition of evergreen broadleaved and coniferous tree species in mid-subtropical China: dynamics of dry mass, nutrient and organic fractions,” *Plant Soil*, vol. 338, no. 1–2, pp. 311–327.
13. Lu C., Chen S., Jiang Y., Shi J., Yao C., and Su X. 2018. “Quantitative analysis of riverbank groundwater

flow for the Qinhuai River, China, and its influence factors," *Hydrol. Process.*, vol. 32, no. 17, pp. 2734–2747.
14. McMahon J.M. *et al.*. 2020. "Vegetation and longitudinal coarse sediment connectivity affect the ability of ecosystem restoration to reduce riverbank erosion and turbidity in drinking water," *Sci. Total Environ.*, vol. 707, p. 135904.
15. Mao Z. *et al.*. 2012. "Engineering ecological protection against landslides in diverse mountain forests: choosing cohesion models," *Ecol. Eng.*, vol. 45, pp. 55–69.
16. Nath A.J. and Das A.K. 2011. "Decomposition dynamics of three priority bamboo species of homegardens in Barak Valley, Northeast India," *Trop. Ecol.*, vol. 52, no. 3, pp. 325–330.
17. Pollen N. and Simon A. 2005. "Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model," *Water Resour. Res.*, vol. 41, no. 7.
18. Recking A., Piton A., Montabonnet L., Posi S., and Evette A. 2019. "Design of fascines for riverbank protection in alpine rivers: Insight from flume experiments," *Ecol. Eng.*, vol. 138, pp. 323–333
19. Rey F. *et al.*. 2019. "Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration," *Sci. Total Environ.*, vol. 648, pp. 1210–1218.
20. Schmitt K., Schäffer M., Koop J., and Symmank . 2018. "River bank stabilisation by bioengineering: potentials for ecological diversity," *J. Appl. Water Eng. Res.*, vol. 6, no. 4, pp. 262–273.
21. Shen P., Zhang L.M., Chen H.X., and Gao L. 2017. "Role of vegetation restoration in mitigating hillslope erosion and debris flows," *Eng. Geol.*, vol. 216, pp. 122–133.
22. Seitz S. *et al.*. 2015. "The influence of leaf litter diversity and soil fauna on initial soil erosion in subtropical forests," *Earth Surf. Process. Landforms*, vol. 40, no. 11, pp. 1439–1447.
23. Shu A., Duan G., Rubinato M., Tian L., Wang M., and Wang S.. 2019. "An experimental study on mechanisms for sediment transformation due to riverbank collapse," *Water*, vol. 11, no. 3, p. 529.
24. Wang L., Zhang G., Zhu P., and Wang X. 2020. "Comparison of the effects of litter covering and incorporation on infiltration and soil erosion under simulated rainfall," *Hydrol. Process.*, vol. 34, no. 13, pp. 2911–2922.
25. WSDOT. 2005. "Geotechnical design manual M46-03." Washington State Department of Transportation Olympia, WA.
26. Wu T.H. and Watson A. 1998. "In situ shear tests of soil blocks with roots," *Can. Geotech. J.*, vol. 35, no. 4, pp. 579–590.
27. Yuen J.Q., Fung T., and Ziegler A.D. 2017. "Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties," *For. Ecol. Manage.*, vol. 393, pp. 113–138.
28. Zhang H., Zhao Z., Ma G., and Sun L. 2020. "Quantitative evaluation of soil anti-erodibility in riverbank slope remediated with nature-based soil bioengineering in Liaohe River, Northeast China," *Ecol. Eng.*, vol. 151, p. 105840.

Nurlita UNM <nurlita.pertiwi@unm.ac.id>

Decision on manuscript JEENG-02554-2021-02

2 pesan

Journal of Ecological Engineering <kontakt@editorialsystem.com> 20 Agustus 2021 16.24
Balas Ke: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>
Kepada: Nurlita Pertiwi <nurlita.pertiwi@unm.ac.id>

August 20, 2021
JEENG-02554-2021-02
Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Dear Dr. Nurlita Pertiwi,

I am pleased to inform you that your manuscript, entitled: Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia, has been accepted for publication in our journal.

Thank you for submitting your work to us.

Kindest regards,
Prof. Gabriel Borowski
Editor-in-Chief
Journal of Ecological Engineering

Nurlita UNM <nurlita.pertiwi@unm.ac.id> 20 Agustus 2021 19.59
Kepada: "gabriel@borowski.net.pl" <gabriel@borowski.net.pl>

Dear Prof. Gabriel Borowski

Thank you very much for the news. I'm waiting for news about the next process.

Best regards,

Dr. Nurlita Pertiwi

Universitas Negeri Makassar

JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(9), 177–185
https://doi.org/10.12911/22998993/141478
ISSN 2299–8993, License CC-BY 4.0

Received: 2021.07.26
Accepted: 2021.08.25
Published: 2021.09.03

Analysis of Riverbank Stability Due to Bamboo Vegetation in Walanae River, South Sulawesi, Indonesia

Nurlita Pertiwi[1*], Bakhrani Abdul Rauf[1], Muhammad Ardi[1], Mithen Lullulangi[1]

[1] Civil Engineering Education Faculty of Engineering, Universitas Negeri Makassar, Makassar, Indonesia

* Corresponding author's e-mail: nurlita.pertiwi@unm.ac.id

ABSTRACT

Bamboo vegetation is an endemic plant in Indonesia that grows on riverbanks. These plants have the potential to increase shear resistance due to the bond between the roots to the soil. However, an increase in plant weight due to its growth causes additional loads of soil. The condition triggers the release of soil on the slopes and causes riverbank sliding. Therefore, in developing the riparian ecological function, it is necessary to maintain the plants without neglecting the risk of physical damage to the river. This study aimed to estimate the risk of riverbank sliding due to the presence of bamboo plants by utilizing the bamboo vegetation conditions on the Walanae River. It was carried out on the 42.4 km riverbank in the middle area of Walanae watershed. The researchers selected 46 clumps of parring bamboo (*Gigantochloa atter*) as an endemic bamboo in this area and growing in the riverbank. The diameter of the bamboo trunk is the basis for an estimate of the weight of the bamboo clump. Furthermore, a numerical analysis was carried out by taking into account the load and shear resistance on the slope, including the weight of the plant. The research results indicated that bamboo is feasible to be applied for riverbank protection using the soil bioengineering method. The bamboo weight, which is indicated by the number of poles and diameter, significantly affects the stability of the slope. Therefore, the prevention of rising weight by harvesting method is critical to consider in riverbank protection.

Keywords: slope, diameter, weight of bamboo, Walanae River.

INTRODUCTION

As an ecological sub-system, riverbanks are very vulnerable to degradation due to their internal characteristics combination and flow dynamics [McMahon et al., 2020]. Environmental restoration of the river system is one of the ecological protection options by combining the flow and soil characteristics [Rey et al., 2019]. Moreover, the high sedimentation and slides are evidence of the decreasing of the riverbank quality. Internally, it is characterized by soil, vegetation, and aquatic conditions of the river.

In contrast, the river flow dynamics are caused by high rainfall, floods, and sediment transport leads to erosion and riverbank collapse [Recking et al., 2019]. Meanwhile, the function of the riverbank as a regulator of river flow depends on its maintenance [Lu et al., 2018]. Ecologically, the river bank also acts as a riparian and is a transition zone in the aquatic zone, always wet with a terrestrial area that sometimes experiences wet or dry conditions [Schmitt et al., 2018].

The existence of vegetation on the banks of the river dramatically affects the physical processes of natural channels. The growth of plants contributes to riverbank stabilization [Bischetti et al., 2014]. However, the process of protecting slopes and their stability and their relationship to plants has not been a serious concern. The presence of large trees increases the potential for slope movement. Moreover, the dynamics of plant growth are very influential on the success of cliff protection [Cislaghi et al., 2018]. Therefore, temporal plant growth should be an essential consideration in soil bioengineering. The dynamics of root reinforcement are exciting studies in applying environmentally friendly cliff protection [Bischetti et al., 2021].

The plant system that includes root, stem, and leaf has a contribution to the bank stability. This contribution can change in line with the characteristics of the stand and the nature of groundwater retention. The stem and leaf system can minimize splash erosion and reduce the risk of scouring the soil. Furthermore, the root system with its growth dynamics has raised many questions about the potential of roots towards soil stability. Root growth contributes to soil shear resistance [Cislaghi et al., 2017].

The ability of plants to maintain streambank conditions depends on the depth of their roots. The natural mechanism that occurs in vegetation can technically be related to the theory of channel hydraulics. The streambank resistance or cliff reinforcement is better with the presence of plant root networks. Plant roots that coincide with the soil shear plane cause a good interaction with soil reinforcement. On the other hand, channel roughness increases along with plant roots. This condition causes a loss of energy in the flow and reduces the flow velocity. With these two mechanisms, plants strengthen riverbanks internally and externally. Plant roots also reduce external stresses due to river flow [Gasser et al., 2019].

The riverbank root systems also improve stability and maintain geometric bank conditions [Abernethy et al., 2000]. The strengthening mechanism of the cliffs with the presence of plant roots is their ability to act as anchors on the ground. Therefore, they are able to support the riverbank soil mass; moreover, and the vegetation roots produce a more robust soil matrix and increase its stability against the risk of collapse [Wu et al., 1998]. Although the hydrodynamic model of river flow is influenced by riverbank vegetation, this plant spreads the flow pattern in order to reduce speed. As a result, there is a kinetic energy decrease in soil mass, which reduces the risk of its release on riverbanks [Pollen et al., 2005].

The contradictory opinions about the role of plant roots on soil stability describe that: the dynamics of plants and their growth cause an increase in the risk of cliff slides [Cislaghi et al., 2018]. The increase in lateral strength due to root growth is also an interesting consideration in the study of soil bioengineering [Dietrich et al., 2007]. Another study, also described the potential for decreasing soil stability due to riparian plant root systems [Zhang et al., 2020]. The intrinsic properties of the soil or its properties affect the erosion potential of the soil. However, the growth of the root system and the accumulation of litter can change the nature and structure of the soil, which can increase the potential for cliff erosion.

Plant growth is also considered a problem at the risk of rock slides. The interaction between water flow and vegetation on the riverbank was also analyzed with a mechanical approach. The increasing shear forces due to plant growth lead to a rise in the safety factor value at a certain slope. Furthermore, plant growth, which includes roots, twigs, and leaves, practically increases soil mass. Therefore, vegetation growth increases the risk of landslides [Mao et al., 2012] and [Bordoloi et al., 2020]. Moreover, the depth of roots can affect the critical shear stress or facilitate slope failure on the riverbank [Gasser et al., 2020].

This study focused on the risk of cliff collapse due to the growth of bamboo plants along the river. The bamboo grows with various species and develops rapidly due to the dependence of the rhizome root system. Meanwhile, when not controlled, the widespread distribution of underground roots causes sprouts to grow in unwanted places. Its sustainability is due to poor maintenance or improper destruction. Bamboo is an essential part of various community activities such as building houses, traditional marriage ceremonies, and death. Furthermore, its shoots are used as local food ingredients.

The decrease in cliff stabilization on the riverbank was caused by the weight of bamboo plants (W1) and soil mass (W2). The combination of plant and soil mass is described in Figure 1. On the basis of this combination, this research was divided into two objectives. The first objective was to find the weight of bamboo estimated by the diameter of poles. The secondary aim of the study is the risk of collapse. In the slope stabilization study, the mass failure was assessed based on the value of safety factors, which indicates cliff collapse when greater than 1.25 [WSDOT, 2005].

METHODS

Study area

The location of this study was the Walanae watershed which intersects the administrative area of Soppeng Regency. The Walanae River, as the focus of this study, has a watershed area of 740 km^2 and a length of 250 km, which flows from south to north towards the Lake Tempe alluvial.

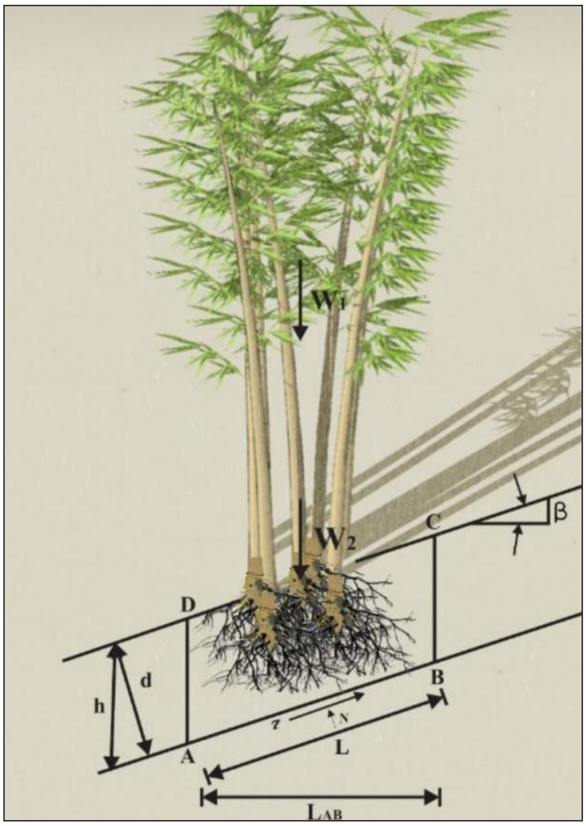

Figure 1. Description of plant weight on cliff stability

Sampling procedure

The measurement of bamboo characteristics was carried out in January 2020 – March 2020. The middle area of the Walanae River was chosen as the sampling location with a river length of 42.4 km. There were 46 clumps of parring bamboo (*Gigantochloa atter)* that became the research sample. As one of the endemic species in Indonesia, bamboo grows in the riverbank of the Walanae River. Figure 3 describes the measurement of pole diameter. It started with the determination of observation points (Fig. 3a). Furthermore, Figure 3b shows the point in the stem height of 150 ± 5 cm [Yuen et al., T. 2017]. Figure 3c shows the measurement of pole diameter using a caliper.

The average value of bamboo diameter forms the basis for calculating the total plant weight using the above-ground biomass equation. Furthermore, the calculation of the importance of bamboo-based on the pole diameter using the AGB (Above Ground Biomass) equation (Eq. 1) [Yuen et al., 2017].

$$AGB = 0.269 \times D^{2.017} \tag{1}$$

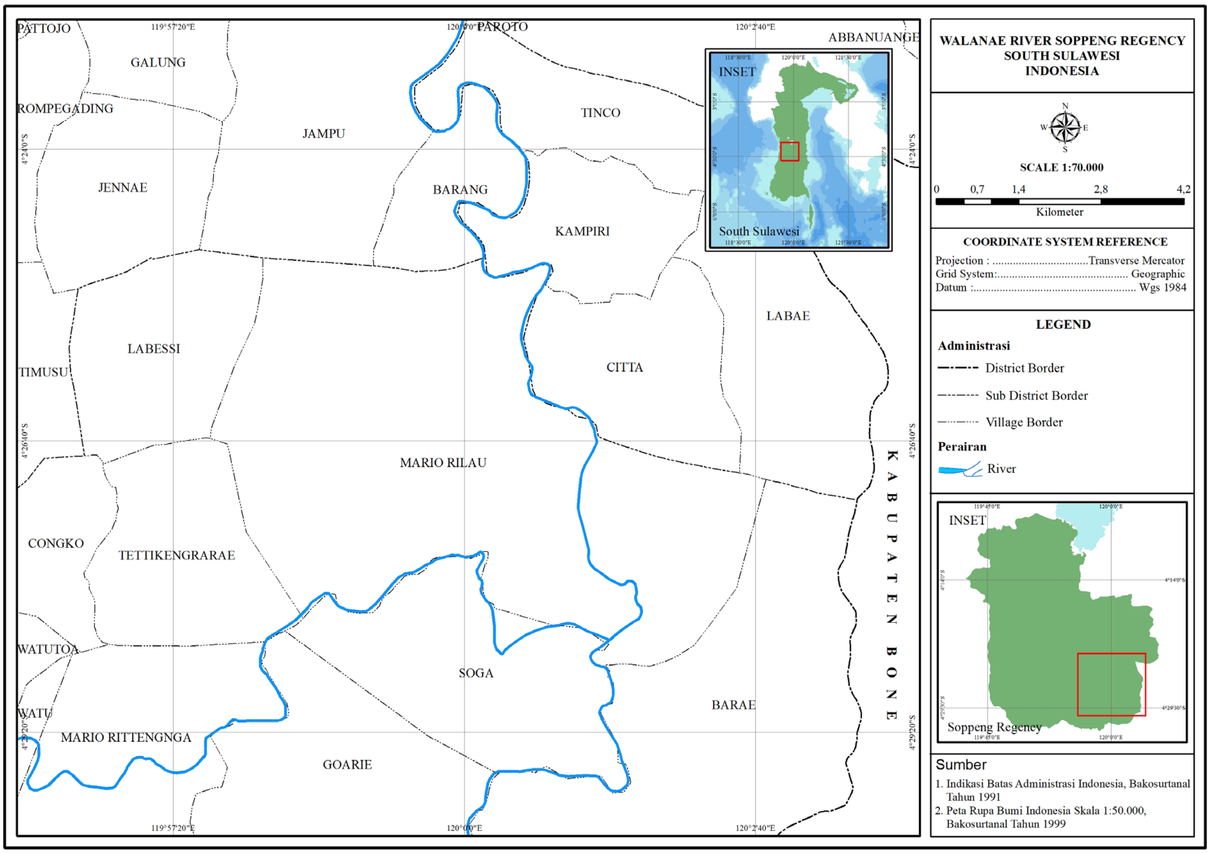

Figure 2. Field site of Walanae River

Figure 3. The Measurement of pole diameter

The weight of the bamboo clump is calculated by the sum of all pole weights in one cluster. Next, the researchers grouped bamboo into three groups, namely Psmall, Pmed, and Plarge. The bamboo weight dataset is arranged from the smallest value to the most significant value. The data structure is divided into three categories. From the results, three types of bamboo were obtained, namely small, medium and large bamboo, based on their weight category.

The target of the research was to describe the incidence of slope landslides by the additional load due to the weight of the bamboo plant. The safety factor (Fs) becomes a marker of the incident. Slope stability analysis used the ratio of shearing resistance to force [Mao et al., 2012] and [Bordoloi et al., 2020]. The numerical test of slope stability using secondary data on soil properties in Soppeng Regency is shown in Table 1. The simulation of the safety factor calculation based on the angle of the slope and size of the bamboo led to the risk of riverbank sliding, and a value greater than 1.25 indicates cliff collapse [19].

$$Fs = \frac{S}{\tau} = \frac{(C' + Cs)L + (W_s^{'} + Wt)\cos\beta\tan\theta'}{(Ws + Wc)\,sin\,\beta} \tag{2}$$

The determination of the input values is presented in the Table 1.

RESULTS

Characteristics of bamboo vegetation in Riparian

Bamboo plants were discovered along the Walanae River. The results of this study showed that most of the bamboo plants were the result of 3–5 years. Due to its very intensive use, bamboo is a commodity with a high selling value. The bamboo is used as building materials for traditional houses for community, local formal events, or other purposes. People tend to choose riverbanks for planting bamboo, because their crops are easily transported to different locations via rivers. In addition, this plant has resistance to standing water due to flooding. Therefore, it is considered suitable for planting in riparian areas. The calculation of pole diameter, number of poles in each clump and plant weight, and the group are presented in Table 2.

Table 2 shows that the maximum number of stems in one clump varies from 16 to 24 poles.

Table 1. Source of secondary data

Variables	Unit	Value	Source
c' (cohesion soil effective)	kPa	14.7	Soil testing data in Walanae River (2018 using ASTM D3080
cs (apparent cohesion due to root)	kPa	7.2	Well-developed grass cover condition [21, 22]
L (bamboo root depth)	m	0.3	
W's (unit weight of soil minus buoyancy)	kN/m^2	Equation $(\partial s - \partial w)h$ ∂s = 13.83 kN/m3 ∂w = 9.8 kN/m3	∂s from soil testing data in Walanae River (2018) using ASTM D854 - 14
W's (unit weight of soil)	kN/m^2	Equation $(\partial s)h$	
B (slope)	o	simulation	
Ø' (friction angle)	o	34.83	Soil testing data in Walanae River (2018) using ASTM D3080

Table 2. Characteristic of bamboo

Characteristic		Maximum	Minimum
Number of poles in one culm		16	27
Diameter pole (cm)		0.4	6.3
Weight of bamboo (kg)		35.514	98.946
The weight of bamboo (kg)	Psmall	35.514	55.393
	Pmed	57.468	74.805
	Plarge	79.210	98.946

The largest diameter is 6.3 cm, and the smallest is 0.4 mm, then the weight of bamboo in one clump is between 35.514 kg and 98.946 kg. Three groups categorize bamboo, namely Psmall, Pmed, and Plarge. The weight of bamboo in the small category is between 35.514 kg and 55.393 kg. Moreover, the weight of medium bamboo (Pmed) is between 57.468 kg and 74.805 kg. Plarge bamboo weights between 79.210 kg and 98.946 kg.

Table 3 show the number of poles (NP), weight, the largest pole diameter (DPmax), and the minor pole diameter (DPmin).

The number of bamboo samples in the Psmall group was 19 clumps with an average weight of 46.538 kg. In turn, Pmed showed an average weight of 63.271 kg from 20 poles, there were only seven clumps in the Plarge group with an average weight of 88.689 kg.

Slope stability analysis

Slope stability is an essential factor in riverbank protection. Meanwhile, vegetation existence on riverbanks is also one of the factors that reduce slope stability. Therefore, the greater the soil mass, the higher the potential of increasing the risk of landslides. This was exacerbated by the addition of vegetation mass which increases along with growth. Furthermore, the estimated weight, which refers to the diameter of the constituent rods, was proven to affect the risk of landslides. Therefore, the value of the safety factor is an indicator of the level of slope stability.

The results of the safety factor analysis on three bamboo groups with various slopes are presented in Figure 4.

Figure 4 shows the decrease of the safety factor value due to an increase in the slope angle. It proves that the larger the slope angle caused, the more extensive the risk of collapse. Psmall gives the most significant Fs value or indicates a small landslide risk in the bamboo with an average weight of 46.538 kg. If the growth of bamboo

Table 3. The weight and diameter of bamboo

The weight and diameter of small bamboo				
No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	17	35.514	0.6	4.8
2	16	38.649	0.6	4.8
3	16	39.397	0.8	4.8
4	16	42.276	0.8	5.4
5	16	42.528	0.5	5.2
6	19	43.637	0.6	4.5
7	19	44.333	0.6	4.6
8	19	45.586	0.8	4.8
9	18	47.804	0.4	4.8
10	19	47.939	0.6	4.7
11	23	47.997	0.4	4.7
12	21	48.083	0.7	4.5
13	18	49.122	0.8	4.8
14	23	49.633	0.4	4.7
15	21	50.598	0.4	4.8
16	24	50.853	0.4	4.2
17	18	52.317	0.4	5.5
18	20	52.560	0.8	5.5
19	18	55.393	0.4	5.8
Weight average = 46.538 kg				

The weight and diameter of medium bamboo				
No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	24	57.468	0.8	5.5
2	24	57.617	0.8	4.8
3	19	57.826	1.1	5.2
4	16	58.382	0.8	6.4
5	24	58.638	0.9	5.8
6	24	59.050	1.0	4.8
7	16	59.066	1.2	6.2
8	17	59.235	0.4	5.8
9	24	59.388	0.5	4.8
10	24	61.306	0.6	5.3
11	24	61.323	1.2	4.8
13	20	61.405	1.3	6.2
14	24	62.689	0.6	5.3
15	19	66.157	0.6	5.8
16	21	71.558	0.7	5.2
17	25	71.695	0.6	5.3
18	27	72.717	0.8	5.2
19	24	73.753	0.6	5.5
20	24	74.805	0.8	5.7
Weight average = 63.271 kg				

The weight and diameter of large bamboo				
No	NP	Weight (kg)	DPmin (cm)	DPmax (cm)
1	23	79.210	0.6	5.5
2	23	80.222	0.8	5.5
3	24	80.584	0.6	5.9
4	24	87.093	0.6	5.5
5	20	88.620	0.8	6.3
6	19	93.404	2.1	6.3
7	20	98.946	1.3	6.3
Weight average = 88.869 kg				

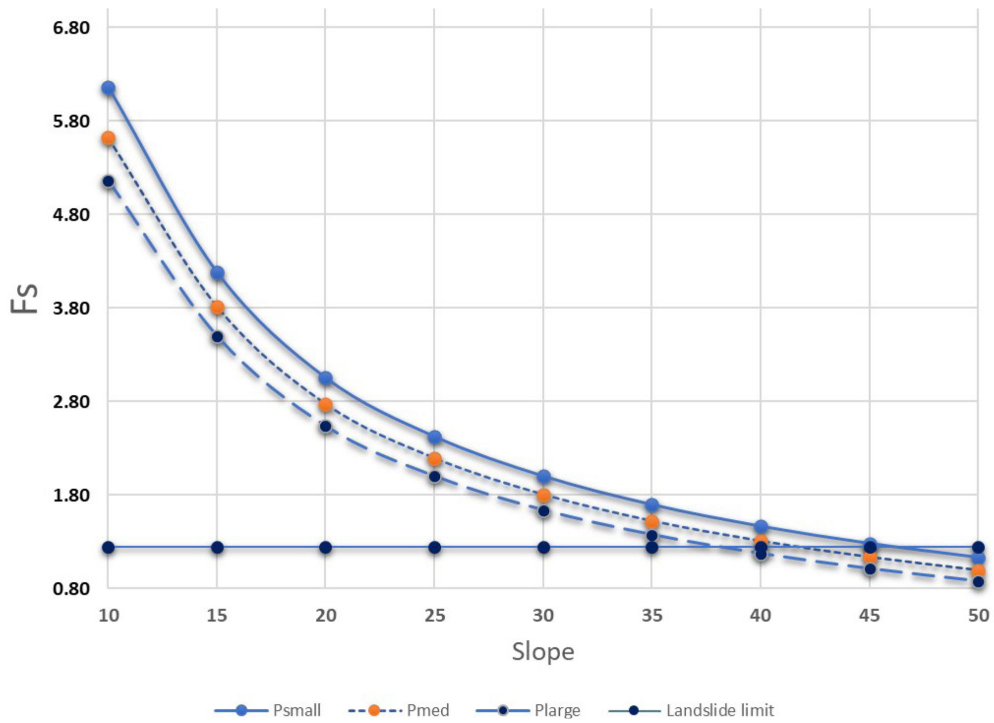

Figure 4. Estimated safety factor due to the weight of bamboo

reaches a greater condition, then the chance of landslides is also higher. The increase in the number of bamboo sticks with a large diameter is a sign of an increased risk of landslides.

At a slope angle of 40°, the presence of plarge bamboo causes landslides. Even worse conditions occur at 45° and 50° angles, and bamboo vegetation causes sliding in the riverbank. This indicates that the slope angle of 40° is not feasible to use bamboo as reinforcement for the cliff.

DISCUSSION

The riverbanks that are equipped with riparian ecosystems contribute to the physical quality of the river. This premise was supported by the Hubble study [Hubble et al., 2010] which stated that plant roots contribute to the reduced risk of landslides due to root strengthening. Therefore, the riparian root system was effective in increasing slope stability. Furthermore, the growth of riparian vegetation usually acts as a floodplain that can maintain the quality of the river. The presence of vegetation minimizes sedimentation as a series of erosion events. As a result, the river bed topography was better preserved and maintained river capacity [Lin et al., 2011] and [Hubble et al., 2010].

Bamboo plants on the riverbank can function as erosion protection. This study has proven that the presence of bamboo can increase the value of the safety factor. The extensive root cohesion causes an increase in soil particle bonding. As a result, the value of a security is even greater. However, the growth or addition of bamboo pole decreases the safety factor of land. The discoveries of this study practically provided a guide for nonstructural river management methods where bamboo vegetation is one of the right choices.

Bamboo, with its distinctive morphology made of several polishes, is relatively easy to manage. The harvesting or releasing of some of its parts is an effort that can maintain the weight of the bamboo plant. Harvesting of parring bamboo at the research location is closely related to the local wisdom of the community. This bamboo is used as a traditional building material and the primary material in local traditional processions. Therefore, parring bamboo is very important for lives of local people. The habit of using bamboo supports soil bioengineering techniques in the Walanae watershed.

This study also proposed the protection of the ground surface to maintain the slope. The safety of surface erosion on riverbanks is an effort to maintain the ground-level slope. Surface erosion or the release of the soil surface due to water flow can be reduced by various methods. Litter covering treatment can improve the soil erosion resistance. The litter layer is very influential in the magnitude of the kinetic energy of rain on the soil surface. Without a surface cover, raindrops can hit the soil surface and cause the surface layer to be released [Wang et al., 2020]. Mechanically, this process takes place continuously and causes an increase in the slope of the slope. Bamboo plants can protect the soil surface from the direct hit of raindrops. Several studies have shown that the thickness of litter layer in the forests regarding weathering of bamboo leaves [Seitz et al., 2015] and [Hairiah, et al., 2006]. Bamboo vegetation with thin and small leaves with a pointed shape and the texture like paper is easy to fall off. The release of leaves from the stems causes accumulation on the soil surface and influences the thickness of the litter layer [Nath et al., 2011]. The idea is to the strengthen reason that the bamboo plant system can also prevent the increase in slopes on riverbanks.

Bamboo weight management and cliff erosion protection also prevent toe erosion from occurring at the base of a slope. [Shu et al., 2019] described that the collapse rate of riverbanks has a positive correlation with flow velocity, water depth, and soil bearing capacity. Figure 5 illustrates the process of toe erosion and cliff collapse. The frictional force of water flow in the foot of cliff trigger the erosion process began with the peeling soil. Figure 5b shows that the presence of bamboo caused the additional weight of soil that is the way the roots of the plants could not carry them. This implies that the significant weight as a burden at the foot of the cliff triggered the collapse. As a result, cliffs collapse, and the vegetation on the riverbanks will also be released.

Soil bioengineering is feasible to be implemented as a riverbank protection technique, as the long the community maintains the growth of bamboo and the slope of riverbank. The sustainability of the parring bamboo vegetation at Walanae Watershed contributes to ecological protection. It prevents the degradation of land and water resources.

CONCLUSIONS

On the basis of the results obtained and numerical analysis of silty riverbank, the authors conclude that the bamboo vegetation on the Walanae riverbanks is divided into three categories based on the weight of clumps. The small category has an average weight of 46.538 kg. The medium type has an average weight of 63.271 kg, and the large bamboo weighing is 88.869 kg. The increase in weight was caused by the addition of the number of stems.

The numerical analysis results indicate that the presence of bamboo vegetation increases the risk of cliff landslides. Therefore, as its weight increases, it contributes to a decrease in the value of the safety factor. The application of bamboo vegetation as slope protection is not possible in the slope angles greater than 40°. The soil bioengineering technique with bamboo vegetation on riverbanks should consider the reduction in the number of polishes in each clump. Harvesting activities are the solution for this technique.

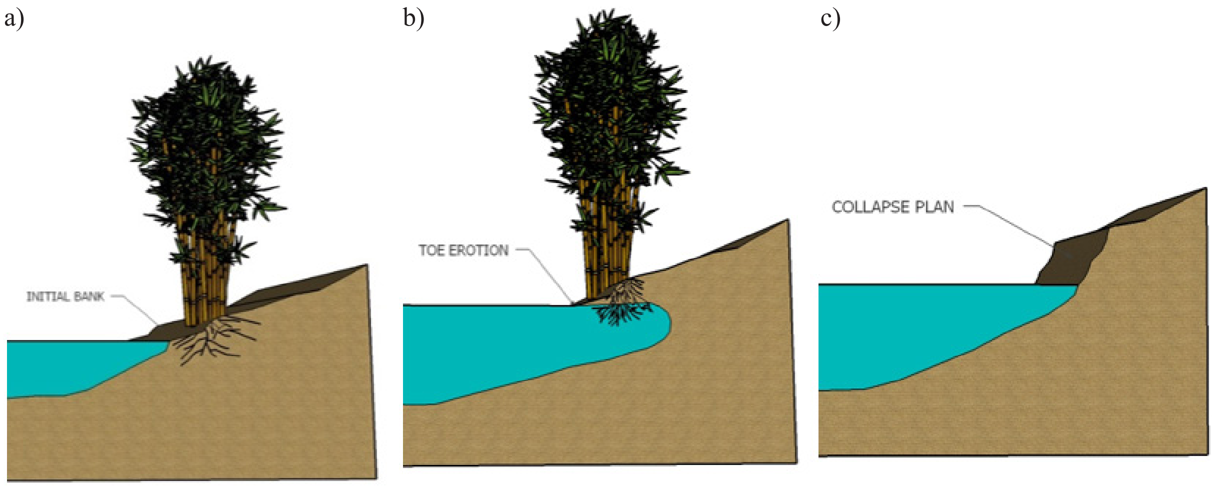

Figure 5. The mechanism of cliff collapse on the riverbank

Acknowledgements

The authors express gratitude for the contribution of funds through the financing scheme "Acceleration of Professors through the Institute for Research and Community Service, Universitas Negeri Makassar Year of 2020".

REFERENCES

1. Abernethy B. & Rutherfurd I.D. 2000. Does the weight of riparian trees destabilize riverbanks? Regul. Rivers Res. Manag. An Int. J. Devoted to River Res. Manag., 16(6), 565–576.
2. Bischetti G.B., De Cesare G., Mickovski S.B., Rauch H.P., Schwarz M., Stangl R. 2021. Design and temporal issues in Soil Bioengineering structures for the stabilisation of shallow soil movements. Ecol. Eng., 169, 106309.
3. Bordoloi S., Ng C.W.W. 2020. The effects of vegetation traits and their stability functions in bio-engineered slopes: A perspective review. Eng. Geol., 105742.
4. Cislaghi A.E., Chiaradia A., Bischetti G.B. 2017. Including root reinforcement variability in a probabilistic 3D stability model. Earth Surf. Process. Landforms, 42(12), 1789–1806.
5. Cislaghi A.E., Chiaradia A., Bischetti G.B. 2018. A probabilistic multidimensional approach to quantify large wood recruitment from hillslopes in mountainous-forested catchments. Geomorphology, 306, 108–127.
6. De Baets S., Torri D., Poesen J., Salvador M.P., Meersmans J. 2008. Modelling increased soil cohesion due to roots with EUROSEM. Earth Surf. Process. Landforms J. Br. Geomorphol. Res. Gr., 33(13), 1948–1963.
7. Dietrich W.E., McKean J., Bellugi D., Perron T. 2007. The prediction of shallow landslide location and size using a multidimensional landslide analysis in a digital terrain model, in In: Chen, CL; Major, JJ, editors. Proceedings of the Fourth International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment (DFHM-4); Chengdu, China, September 10-13, 2007. The Netherlands, Amsterdam: IOS Press. 12.
8. Gasser E. et al.. 2019. A review of modeling the effects of vegetation on large wood recruitment processes in mountain catchments. Earth-Science Rev., 194, 350–373.
9. Gasser E., Perona P., Dorren L., Phillfips C., Hübl J., Schwarz M. 2020. A new framework to model hydraulic bank erosion considering the effects of roots. Water, 12(3), 893.
10. Guo W.Z. et al.. 2020. Telling a different story: The promote role of vegetation in the initiation of shallow landslides during rainfall on the Chinese Loess Plateau, Geomorphology, 350, 106879.
11. Hairiah D.K., Sulistyani H., Suprayogo D., Purnomosidhi P., Widodo R.H., Van Noordwijk M. 2006. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung, For. Ecol. Manage., 224(1–2), 45–57.
12. Lin C., Yang Y., Guo J., Chen G., Xie J. 2011. Fine root decomposition of evergreen broadleaved and coniferous tree species in mid-subtropical China: dynamics of dry mass, nutrient and organic fractions. Plant Soil, 338(1–2), 311–327.
13. Lu C., Chen S., Jiang Y., Shi J., Yao C., Su X. 2018. Quantitative analysis of riverbank groundwater flow for the Qinhuai River, China, and its influence factors. Hydrol. Process., (32)17, 2734–2747.
14. McMahon J.M. et al.. 2020. Vegetation and longitudinal coarse sediment connectivity affect the ability of ecosystem restoration to reduce riverbank erosion and turbidity in drinking water. Sci. Total Environ., 707, 135904.
15. Mao Z. et al.. 2012. Engineering ecological protection against landslides in diverse mountain forests: choosing cohesion models, Ecol. Eng., 45, 55–69.
16. Nath A.J. & Das A.K. 2011. Decomposition dynamics of three priority bamboo species of homegardens in Barak Valley, Northeast India, Trop. Ecol., 52(3), 325–330.
17. Pollen N., Simon A. 2005. Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model. Water Resour. Res., 41(7).
18. Recking A., Piton A., Montabonnet L., Posi S., Evette A. 2019. Design of fascines for riverbank protection in alpine rivers: Insight from flume experiments. Ecol. Eng., 138, 323–333.
19. Rey F. et al.. 2019. Soil and water bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. Sci. Total Environ., 648, 1210–1218.
20. Schmitt K., Schäffer M., Koop J., Symmank. 2018. River bank stabilisation by bioengineering: potentials for ecological diversity, J. Appl. Water Eng. Res., 6(4), 262–273.
21. Shen P., Zhang L.M., Chen H.X., Gao L. 2017. Role of vegetation restoration in mitigating hillslope erosion and debris flows. Eng. Geol., 216, 122–133.
22. Seitz S. et al.. 2015. The influence of leaf litter diversity and soil fauna on initial soil erosion in subtropical forests, Earth Surf. Process. Landforms, 40(11), 1439–1447.
23. Shu A., Duan G., Rubinato M., Tian L., Wang M., Wang S. 2019. An experimental study on mechanisms for sediment transformation due to riverbank collapse, Water, 11(3), 529.
24. Wang L., Zhang G., Zhu P., Wang X. 2020. Comparison of the effects of litter covering and incorporation

on infiltration and soil erosion under simulated rainfall. Hydrol. Process., 34(13), 2911–2922.

25. WSDOT. 2005. Geotechnical design manual M46-03." Washington State Department of Transportation Olympia, WA.
26. Wu T.H. & Watson A. 1998. In situ shear tests of soil blocks with roots. Can. Geotech. J., 35(4), 579–590.
27. Yuen J.Q., Fung T., Ziegler A.D. 2017. Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties, For. Ecol. Manage., 393, 113–138.
28. Zhang H., Zhao Z., Ma G., Sun L. 2020. Quantitative evaluation of soil anti-erodibility in riverbank slope remediated with nature-based soil bioengineering in Liaohe River, Northeast China, Ecol. Eng., 151, 105840.